Coastal Geography Conference

18 FEBRUARY 1954

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PREFACE

The principal objectives of the Coastal Geography research program of the Office of Naval Research are to provide new scientific information on the coastal zones of the world, and to enable a better understanding of coastal processes and changes. The complexity of coasts, their diversity and seemingly unsystematic alterations, have long intrigued scientists. However, until recently, comparatively few scientists devoted their efforts to the solution of the many apparent and innumerable obscure problems associated with this land and water zone. Too little was, or in fact, is known of the processes and mechanisms of change. Although a considerable body of theoretical knowledge slowly accumulated, it was not accompanied by a commensurate amassing of precise measurements and observations. World War II brought into clear focus not only the need for specific information on individual coasts, but also, and more important from the research view, the lack of fundamental knowledge concerning coasts in general. The increased and urgent demand for information brought many new scholars to this field. Wartime studies, which frequently took on the aspects of expediency, did much to pinpoint and clarify the basic scientific problems. Today, partly under the sponsorship of the Office of Naval Research, appreciable, yet insufficient, effort is being directed toward the solution of these problems which cut across the various disciplines of science and involve aspects of essentially all the sciences.

Included in the program of coastal research as conducted by the Geography Branch of ONR are studies ranging from detailed examinations of individual coasts to classification and description of coastal zones on a world basis. A wide variety of scientific and engineering skills, techniques, and procedures are employed. New methods are being developed and new applications are being made of standard techniques. It is to be expected that such a broad and varied program will provide the Navy with many of the answers it seeks. There is also promise of substantial contribution to fundamental scientific knowledge.

To assure success of this program, it is felt desirable from time to time to bring together some of the scientists participating in the ONR project to present their research findings even though these may be preliminary and tentative. This allows the scientists and the potential users among the military services to become acquainted with the progress that is being made, the trends and developments, and to make suggestions for strengthening and improving the program.

The papers published here were presented at the Conference on Coastal Geography. It is earnestly hoped that comments concerning individual tasks or the research program as a whole will be directed to the Geography Branch.

The Office of Naval Research appreciates the fine spirit of cooperation, service, and interest of the Earth Science Division of the National Academy of Sciences—National Research Council whose untiring effort made this conference possible.

Evelyn L. Pruitt

EVELYN L. PRUITT
Geography Branch
Office of Naval Research

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COASTAL GEOGRAPHY CONFERENCE

Sponsored by the
Geography Branch, Office of Naval Research
and the
NRC Committee on Geography, Advisory to ONR

February 18, 1954

NAS-NRC Building
Lecture Room

Chairman: Richard J. Russell
Louisiana State University

Morning Session

Afternoon Session

OBJECTIVES AND METHODS OF PHOTO INTERPRETATION RESEARCH ON THE MEDITERRANEAN BASIN

Charles V. Crittenden
Virginia Geographical Institute

Contract N7onr-37203
Task NR 089-031

Since the early nineteen forties, more than twelve years of the middle portion—the most mature—of the careers of numerous American scientists have been associated more or less directly with problems of the United States Government under emergency and near emergency conditions. This experience has led, irregularly and during less hectic moments, to some comparisons of notes and ideas on such matters. Some of these scientists on both the Governmental and scientific sides have wondered if worthwhile basic parts of such work could not be planned and developed, with mutual advantages, in advance of more acute emergencies. Each of us here today probably finds numerous persons present with whom we have had such exchange of ideas; and this appears to be one of the reasons for the present symposium.

Problems involving the character of areas repeatedly trouble the minds of men, especially during emergencies. Plans have to be formulated and decisions made on policy activities and operations ranging from individual to major strategy, and including diplomatic and military aspects. Intelligence has to be expanded and new hands quickly trained in its work which commonly involves questions of places and area relationships. Our war-time and post-war experience, as geographers and related scientists drawn in to aid with such problems, led us to depend upon or develop new materials like maps, map intelligence, and written area reports when beset by requests for aid in matters of policy and action of men in areas.

During and after the war, I became more and more struck with the idea that the growing files of aerial photographs offered a little-used but potentially valuable source of basic area knowledge for those who could develop an understanding of the patterns. Techniques for use of such photographs were advancing rapidly in several specialized fields, but little of this was done in area studies. The Navy, the Air Force, and civilian agencies began to experiment with "photo-geographics" and interpretation keys of one or two elements (i.e., "Pacific Landforms and Vegetation") or of striking pattern portrayals within large areas ("Photo Interpretations of Arctic Territories"). Neither of these types of outstanding work or manual went very far in telling where the considered patterns or features were distributed or how they were intermingled with other features of such large areas.

Scientific and technical experiment with aerial photographs developed rapidly but irregularly on both sides of the Atlantic. We found that German scientists had gone farther in the direction of area studies in their "Forschungstaffel"—particularly in their analogous area studies, some of which were focused upon coastal margins. Many agencies in this and other countries became interested in keys for the interpretation of aerial photographs. Few of these keys, however, were pointed toward being area keys; and yet, aerial photographs portray, better than maps or written accounts, the <u>contextual</u> character of things together which is the reality of areas in which men must live and operate.

Several experimental aspects of area study and the transmittal of such knowledge are combined in our investigative project.

<u>First</u>—We are experimenting with methods for the use by scientific personnel of files of air photographs as a main source, along with documents and maps, of contextual information

about areas, such as the Mediterranean coastal zones. This technique might well apply for future use on areas which are becoming less readily studied through field observation and normal research methods.

Second—Experiments are being conducted with what we have sometimes called "photogeographical" techniques for analyzing and transmitting our understanding of coastal zone patterns and problems. It is planned that the achievements of this research be measured, in a considerable degree, by summarizing graphic manuscripts for ready conversion by publication into manual form for use by the Navy. Thus we will today give you a representative sampling of the graphic portrayals of Mediterranean coastal zone patterns which we are now completing while initiating work on coastal zones of a second sea area—the Black Sea. These keys are intended to be of worth to photo interpreters, from trainee to professional, and also of more general value in two ways: (a) to transmit a sound understanding of coastal zone areas to other personnel as background for judgements at various levels of responsibility, (b) to take a sound place, if desired, in developing programs of basic intelligence centered on important sea areas.

Third—We are consciously attempting to find a way around one of the oldest difficulties in the field of area studies. Some 40 years ago, William Morris Davis said, "There can be little question that the least satisfactory feature of regional description lies in the necessity of presenting in separate, successive paragraphs or pages the many kinds of things that occur together in natural but unsystematic groupings." We wish that we could report as completed a brilliant, new, briefer, and more forceful technique for transmitting an understanding of areas. We still have to consider or present many of the different things in separate successive paragraphs. However, we do feel that our present results with combined photo and graphic portrayals with a minimum of written words warrant continuing hard work and support from the varied scientific, institutional, and Governmental quarters which make such project research possible. We feel that our present results are far more than the negative which would be proper to report after fruitless research. Perhaps the best summary can be made by the hope that our developing technique will become even a fraction as forceful and attractive a graphic medium as the ubiquitous and, in some cases, rather sinister "comic books" have become for the youth of our land.

A consideration of other and interesting experimental aspects of the work is thought less essential at the present meeting. Let us turn to samples of graphics, especially some from the Mediterranean research.

Patterns of aerial photography are becoming less strange to many people. Slide 1 (an aerial view of Washington, D. C.)* shows that obliques, even near-vertical obliques, now appear in the newspaper because of their beauty in pattern and designs shown. The vertical view remains, however, technically most valuable and most difficult to interpret.

From the outline and end-plate diagram at hand you can observe that we are forcing ourselves to organize and present in graphic report the result of a large amount of research. In doing this we have found it necessary to adopt, modify, and use in tentative form, several methods and organizational plans which some of you, rightly, may consider subjects of your current research and investigation. In some cases, we have done this inadvertently; in others, we choose and use the plan in advance of your developing conclusions. Much better results should ensue from our closer exchange of ideas in the future.

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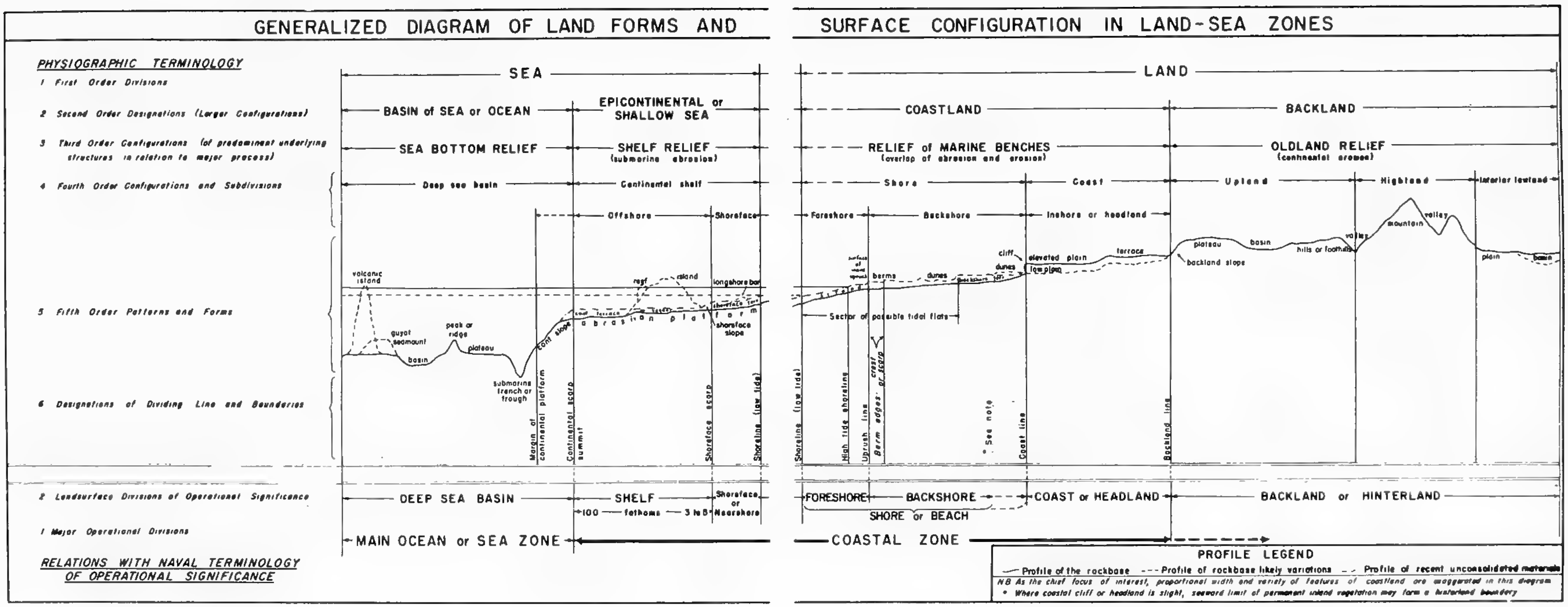
*This slide was presented at the conference but is not reproduced here.


GENERALIZED DIAGRAM OF LAND FORMS AND SURFACE CONFIGURATION IN LAND-SEA ZONES
PHYSIOGRAPHIC TERMINOLOGY
1 First Order Divisions
2 Second Order Designations (Larger Configurations)
3 Third Order Configurations (of predominant underlying structures in relation to major process)
4 Fourth Order Configurations and Subdivisions
5 Fifth Order Patterns and Forms
6 Designations of Dividing Line and Boundaries
SEA
LAND
BASIN of SEA or OCEAN
EPICONTINENTAL or SHALLOW SEA
COASTLAND
BACKLAND
SEA BOTTOM RELIEF
SHELF RELIEF (submarine abrasion)
RELIEF of MARINE BENCHES (overlap of abrasion and erosion)
OLDLAND RELIEF (continental erosion)
Deep sea basin
Continental shelf
Shore
Coast
Upland
Highland
Interior lowland
Offshore
Shoreface
Foreshore
Backshore
Inshore or headland
volcanic island
guyot
seamount
basin
peak or ridge
plateau
submarine trench or trough
cont slope
abrasion platform
reef
island
longshore bar
shoreface slope
berms
dunes
cliff
elevated plain
low plain
terrace
plateau
backland slope
basin
hills or foothills
valley
mountain
valley
plain
basin
Sector of possible tidal flats
Margin of continental platform
Continental scarp summit
Shoreface scarp
Shoreline (low tide)
Shoreline (low tide)
High tide shoreline
Uprush line
Berm edges crest or scarp
* See note
Coast line
Backland line
RELATIONS WITH NAVAL TERMINOLOGY OF OPERATIONAL SIGNIFICANCE
2 Landsurface Divisions of Operational Significance
1 Major Operational Divisions
DEEP SEA BASIN
SHELF
100 fathoms
3 to 5
Shoreface or Nearshore
FORESHORE
BACKSHORE
SHORE or BEACH
COAST or HEADLAND
BACKLAND or HINTERLAND
MAIN OCEAN or SEA ZONE
COASTAL ZONE
PROFILE LEGEND
Profile of the rockbase
Profile of rockbase likely variations
Profile of recent unconsolidated materials
NB As the chief focus of interest, proportional width and variety of features of coastland are exaggerated in this diagram
* Where coastal cliff or headland is slight, seaward limit of permanent inland vegetation may form a backland boundary

Virginia Geographical Institute
February 1954

WORKING OUTLINE—SUBJECT TO REVISION
(End Plates—Generalized Diagram)

COASTAL ZONES OF THE MEDITERRANEAN BASIN
Photo Keys of Salient Surface Patterns

PART I: INTRODUCTION—AIDS & TECHNIQUES
(Pages 1-99 allocated; about 40 to 50 two-page presentations.)

Acknowledgements
Foreword
Aim and Purpose
Map of Mediterranean Coastal-Zone Types faced by Table of Contents
Definitions, Aids, and Points of View: Presentation, Graphic, and other Aids to Photo Interpretation in Mediterranean Coastal-Zone Regions.
1. Coastal Zones as distinctive regions.
2. Terminology and Definitions:
   a. General and Generalized Diagram of Land Form and Surface Configuration in Land-Sea Zones.
   b. Glossary and Index of Technical Terms.
3. Explanation of cross-reference methods in these manuals.
   a. Table of contents on page facing the map of Coastal-Zone Types and Distribution.
   b. Place-name index at end of Part I.
   c. Combined glossary of technical terms and topical index.
   d. Patterns and topics on particular photo keys are commonly cross-referenced to related keys.
4. Types of presentation and their orientation practices in regional photo representations.
5. Distributions and map graphics as aids to Mediterranean photo keys:
   a. Map of Coastal-Zone Types and Distributions.
   b. Hypsometric Relief Map.
   c. Regional Map of Predominant Land Form, Land Structure, and Sea-Bottom Configuration.
   d. Climatic Types.
   e. Generalized Terrain Types, 1:15,000,000.
   f. Terrain Types, 50 sheet map at 1:1,000,000, Legend and Index.
   g. Block Diagrams as interpretive aid in understanding Mediterranean surface patterns.

Survey and Elemental Analysis of Mediterranean Region as a whole.
1. General Statement: of major or salient elements, their distributions and regional combinations.
2. Mediterranean surface configurations considered as coastal-zone character.
3. Climate and related patterns of Vegetation and Drainage as coastal-zone character.
4. Salient Cultural Patterns.

General Statement of the Three Major Divisions of Mediterranean Coastal Zones Selected for Use in these Manuals. Characteristics and subdivisions exemplified for:
1. Low to Moderately Sloping Coastal Zones (Green areas on map)
   a. "Coastal Plain" Coastal Zones.
   b. "Low Platform" Coastal Zones.
   c. "Alluvial Plain" Coastal Zones.
2. Abruptly Rising Coastal Zones (Red patterns on map)
   a. Hilly Upland Coastal Zones.
   b. Plateau Coastal Zones.
   c. Mountain Coastal Zones.
3. Complex Coastal Zones (Brown or orange on map)
   a. Compactly Variable Combinations of Low and Abrupt Types.

b. Volcanic Coastal Zones.
c. "Ria Shore" Coastal Zones.
(End Plates—Generalized Diagram)

PART II: LOW TO MODERATELY SLOPING COASTAL ZONES
(of Mainland and Larger Islands—Pages 100 thru 203 or about 50 two-page presentations)

General—General Introductory Statement and Graphic Illustration of the Three Kinds of Low Coastal Zones of the Mediterranean. Areas appear in green on map.

1. "Coastal Plain" Coastal Zones.
   102-115 Tunisia—largely Eastern Basin and Semiarid Climate.
   116-129 Levant—Eastern Basin and Subhumid, Semiarid, Arid.
2. "Low Platform" Coastal Zones.
   130-133 Italy—Eastern Basin and Subhumid
   134-143 East Tunisia, Gabes Shottes-Eastern Basin and Arid.
   144-149 Libya—Eastern Basin and Arid.
   150-153 West Egypt—Eastern Basin and Arid.
3. "Alluvial Plain" Coastal Zones.
   154-159 Egypt, Nile Delta—Eastern Basin and Arid.
   160-163 Northeastern Greece—Eastern Basin and Subhumid.
   164-167 Greece, Peloponnesos—Eastern Basin and Subhumid, Highland.
   168-173 Albania—Eastern Basin and Humid, Subhumid.
   174-178 Italy, Po Delta—Eastern Basin and Subhumid.
   179 Albania, Soni Strip—Eastern Basin and Subhumid.
   180-181 Italy, Agri River—Eastern Basin and Subhumid.
   182-183 Italy, Latinum—Western Basin and Subhumid.
   184-185 France—Western Basin and Subhumid.
   186-189 Spain—Western Basin and Semiarid, Subhumid.
   190-203 Algeria—Western Basin and Subhumid.
   (End Plates—Generalized Diagram)

PART III: ABRUPTLY RISING COASTAL ZONES
(of Mainland and Larger Islands—Pages 204 thru 323 are allocated for about 60 two-page layouts)

General—Introductory Statement and Graphic Illustration of the Three Kinds of Abruptly Rising Coastal Zones of the Mediterranean. Areas appear in red on map.

1. Hilly Upland Coastal Zones.
   206-209 Italy, Ancona-Vasto—Eastern Basin and Subhumid.
   210-219 Western Greece—Eastern Basin and Subhumid, Highland.
   220-221 Cyrenaica—Eastern Basin and Semiarid.
   222-223 Sardinia—Western Basin and Subhumid.
2. Plateau Coastal Zones.
   224-227 Eastern Spain—no photography available.
3. Mountain Coastal Zones.
   228-231 Morocco, Rif-Atlas—Western Basin and Subhumid, Highland.
   232-240 Algeria—Western Basin and Subhumid, Highland.
   241 Spain, Pyrenees—Western Basin and Subhumid, Highland.
   242-245 Southeast Spain—Western Basin and Subhumid, Highland.
   246-247 France, Nice—Western Basin and Subhumid, Highland.
   248-251 France-Italy—Western Basin and Subhumid, Highland.
   252-253 Italy, Spezia—Western Basin and Humid, Highland.
   254 Sicily—Western Basin and Subhumid, Highland.
   255 Sicily, Southeast—Eastern Basin and Subhumid.
   256-271 Yugoslavia, Karst—Eastern Basin and Humid, Subhumid, Highland.
   272-281 Yugoslavia—Eastern Basin and Humid, Highland.
   282-287 Albania—Eastern Basin and Humid, Highland.
   288-289 West Greece—Eastern Basin and Humid, Highland.
   290-295 Gulf of Korinth—Eastern Basin and Subhumid, Highland.
   296-305 SW Peloponnesos—Eastern Basin and Subhumid, Highland.

PHOTO INTERPRETATION OF COASTAL ZONES OF DALMATIA

Geza Teleki
Virginia Geographical Institute

Contract N7onr-37203
Task NR 089-031

Mr. Crittenden has discussed the aims, methods, and systems of our project in general. Now I will try to present the application to a specific case. I have selected for this purpose the coastal zones of Dalmatia, also called the Dinaric Karst. This region is an ABRUPT type, MOUNTAIN sub-type coastal zone.

About one-quarter of the Mediterranean coastal zone areas has a limestone rockbase. More or less conspicuous karstland topography can be detected in about one-half of these limestone regions. A typical region with karstland topography is that of the Adriatic and Ionian Seas. This region presents different coastal zone types, for example:

1. Low to moderately sloping coastal zones—sub-type: Low Platform which can be seen on Slide No. 1* (layout page No. 131),* the heel of the Italian peninsula, the region of Puglia;

2. Abrupt coastal zones—sub-type: Mountain, to be seen on Slides Nos. 2 & 3 (layout pages Nos. 296-297) and representing the SW Peloponnesos;

3. Complex coastal zones—
   a. Sub-type: Combination low and abrupt, as shown on Slides 4 & 5 (layout pages Nos. 336-337), a region of Central Western Greece;
   b. Sub-type: Ria, represented by Slides 6 & 7 (layout pages Nos. 478-479) showing coastal zones of Istria.

The slides shown so far illustrate the fact that karst topography is not limited to one specific coastal zone type.

While investigating a great number of air photos of the Mediterranean, we were convinced that regional treatment based on interpretation of air photographs could be used successfully by the Navy. Topical treatment based on types of climate, structure, vegetation, etc. alone, although it improves the analytical study of regions, tends to suppress somewhat the contextual understanding. The interpretation of air photos involves the necessity of dealing with intermingling factors on one or a few photos. The understanding of the intermingling of these factors, as seen through aerial photographs, is essential to a grasp of regions. Therefore, our aim was based on an approach to comparative study of landscape elements and landscape types.

Yet topical treatment forms a valuable aid within the frame of our work. This holds true mainly for areas with unknown or generally unfamiliar features to U. S. citizens. In such cases we have introduced the regional interpretation of a characteristic area by a series of photos presenting the characteristic surface features. But even in such cases the topical treatment is that of a single region of the Mediterranean. The treatment of the Dalmatian Karst therefore contains expressly the karst topography of Dalmatian coastal zones.

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*These slides were presented at the conference but are not reproduced here. These layout page numbers refer to the pages listed in the outline presented in the preceding paper [Ed.].

The topical treatment of Dalmatia's karstlands contains two sections, each with two subsections:

1. Specific physiographic patterns:
   a. Karst features and terrain forms.
   b. Karst shoreline types.

2. Characteristic cultural patterns:
   a. Cultivation patterns.
   b. Settlement types.

Slide 8 (layout page No. 256) shows the Dalmatian karst features and their local terminology. It also reveals that there is no true relation between precipitation and rock type or between structure and karst landforms.

Slide 9 (layout page No. 257) shows a typical karstland with those karst features marked which generally can be seen on smaller scale air photos. Such features include dolines, uvalas, karst canyons, dry valleys, and poljes.

Slide 10 (layout page No. 258) is a detail of the previous slide. Larger scale naturally shows features like dolines better. One of these dolines is represented by a groundshot. Another groundshot shows the lapies, which cannot be detected on air photos. Yet these are of great importance because they may act as a barrier to cross-country movement and trafficability.

Slide 11 (layout page No. 259) is a forested karst region of the backland of northern Dalmatia. The presence of karst topography is discernible solely by the "doline pattern." The groundshots show an uvala easy to detect on air photos, whereas the bogaz shown on the other groundshot does not show up on air photos or is much too often undiscernible.

Slide 12 (layout page No. 261) shows a polje of the northern forested karstlands of Dalmatia. Its presence can be seen mainly by the checking of drainage which disappears in the center of the polje and shows thus subsoil karst structure, rather than by the groundshot taken at early spring time and showing the flooded stage. Seasonal flooding again is of military importance but can be detected on air photographs only if air photos taken at different seasons are available.

Slide 13 (layout page No. 262) shows a karst canyon as a detail of slide 9. These karst canyons commonly contain routes or trails important to communication. The other photo of this layout shows a section with submerged canyons which are generally good navigation channels to larger sheltered bays. The ground shot shows a number of huge springs, which indicate indirectly the existence of a huge underground cavern system. Oblique shots taken from the right angle could show this kind of karst feature.

Slide 14 (layout page No. 265) shows karst plateaus and their escarpments. The ground shots show the rough and dissected surface. This surface and the escarpments with their steep walls facing the sea are considerable barriers to cross-country movement and trafficability. The broken surface cannot be seen on air photos, but generally appears as wide grey patches.

Slide 15 (layout page No. 267) shows karst shoreline types. The four upper stereos are of limestone coasts; the two lower ones are coasts composed of clay. Among the four upper views, the two top stereos show shoreline patterns of the northern Dalmatian karst. The two lower are of the southern area. In the northern area, islands lie off the mainland shore. In the southern area no islands shadow the shores. Wave erosion is therefore different and produces the highly intricate "lacy" shoreline of southern Dalmatia. These factors may be of importance to landing operations.

Slide 16 (layout page No. 270) presents cultivation patterns of the Dalmatian coastal zone area. Cultivation pattern of a barren and a forested karst region is shown on the two lower stereos. The upper left stereo represents a pre-war Italian, the upper right stereo a pre-war

Croatian cultivation type. Note difference between the two—the intensity of cultivation of the Italian area as against the desolate character of the Croatian area. This may be of importance to the military since it reflects the differing skill and standards of the population as well as population density factors.

Slide 17 (layout page No. 271) shows a cultural barrier to cross-country movement; "stone hedges" built by the population to preserve the little top-soil against heavy runoff, but also to get rid of the tremendous amount of rock which certainly does not facilitate plowing.

Slide 18 (layout page No. 272) presents a settlement of the southern Dalmatian coastal zone, the town and port of Omis.

Slide 19 (layout page No. 273) presents a similar, although bigger settlement of the northern Dalmatian coastal zone, Rijeka (Fiume). Note on both slides the difficulty to harbor building, the abruptness of the coasts and the backland, and the exposure to winds and waves. Railways and other routes wind considerably, and viaducts have to be built over karst canyons.

Slides 20 and 21 (layout pages Nos. 274-275) show the northern Dalmatian coastal zone type by means of block diagrams and vertical stereo pictures.

Slides 22 and 23 (layout pages Nos. 276-277) show the same for the southern Dalmatian coastal zones. These last four slides may give an impression of the general character of an abrupt coastal zone type, mountain sub-type, of the Mediterranean area. Because mountain ranges run parallel to the shoreline and plateau escarpments have the same direction, landward operations become somewhat difficult. Sometimes better circumstances prevail in areas where the structural strike of mountains is oblique or vertical to the shoreline, as in western Turkey or Spain.

In general, abrupt mountain coastal zones with karst topography present real barriers to cross-country movement, especially where the access is by rocky and steep coasts exposed to the wave and current action.

SUMMARY OF DISCUSSION OF PAPERS BY CRITTENDEN AND TELEKI

The discussion of the two papers indicated it was not considered important in this study of the Mediterranean Basin to make a systematic classification of shoreline types. No classification system had been developed specifically for this area. However, where the shoreline type was regarded as important to the regional description, it was taken into consideration. Although some of the coastlines, such as in parts of Dalmatia and Istria, were apparently drowned coasts, no attempt had been made to determine whether coasts were submerging or emerging. This would have involved much more time in research than was warranted to fulfill the objectives of the project. The coastal descriptions are intended to define the pattern and characteristics essential in operational planning, rather than trace the development of the coasts.

CORRELATION OF SHORELINE TYPE WITH OFFSHORE CONDITIONS IN THE GULF OF MEXICO

W. Armstrong Price
Agricultural and Mechanical College of Texas

Contract N7onr-48706
Task NR 388-009

The project on which I have been working is an attempt to correlate shoreline type with offshore conditions. It has been limited to the Gulf of Mexico where there is a broad or fairly broad continental shelf. So far I have been working necessarily on the basic science phase of the problem. Next will come the applied phase which has special interest for the Navy. The objective of that phase is to find some of the index conditions in the offshore area, which would indicate the type of shoreline that you would expect if you landed on a little-known coast, and vice-versa: knowing something about the shoreline, you could predict what you would encounter off shore. This applied phase can be started now because much of the basic information which I needed has just arrived.

The shoreline is the place where land and ocean meet. Under peacetime conditions, the geography and physiography of the land are easily determinable. For our project we should find out what the ocean has done in modifying the land surface, or in controlling any extensions of the land which are taking place contemporaneously, such as deltaic growth. That is a traditional, well-known situation with geologists and geomorphologists.

My previous experience was in the study of the deltaic Pleistocene coastal plains of the Gulf of Mexico, trying to learn their nature—that is, what were the characteristics easily determinable from the surface so as to find out the normal, and then discover the abnormal on a small scale, for example, surface anomalies of the oil-field structure type and size. For instance, the deltaic plains have characteristic slopes depending on such factors as the energy of the streams that deposited them, the coarseness of grain and volume of the sediment, and the slope of the land. We have found that each of the five successive deltaic plains of the Gulf coast has its own slope and own topographic characteristics. After determining the normal characteristics of the plains, the objective was to find the abnormalities caused by structural uplift. These appear as domes, up-warped ridges, and scarps.

In coming to this project of the offshore area, I thought that we might find some such basic control. Adopting the viewpoint of the oceanographer, a strictly geophysical one, my approach was to determine the wave-energy relationships on the continental shelf, get actual figures on the energy, and determine spectra of wave energy across the shelf; that is: (a) the total energy of the deep water wave as it approaches the edge of the continental shelf, and (b) the degree to which that energy is dissipated as it crosses the shelf. With this done, we might find out what the residual energy does to the shoreline. In other words, would it be possible some day to set up a classification of shorelines and shelf zones based on the amount of energy used in developing them? Of course there would be many other factors to consider besides those mentioned, and we would find many varieties and sub-varieties of coasts, but might there not be a basic relationship between the amount of energy and the type of shoreline?

At first I used relative energy values, as it took considerable time to find the right people to make the numerical energy computation on a regional basis. The usual approach of the oceanographer is extremely time-consuming and expensive—to determine in detail the amounts of energy that are going to be thrown against a single structure built at the shoreline. Therefore, we had to find a method of determining the energy from a regional standpoint.

We approached the problem from the viewpoint that if we could take the meteorological data on the region, the duration and velocity of winds, and determine the wave energy from all the winds which would develop waves at different parts of the coast and the variations from one part of the coast to the next, we would have quantitative energy figures which would apply to the shoreline study.

The first consignment of the quantitative energy figures came in as I was writing this report. I apologize for not having the report coordinated better, and not having the final correlation table for the Navy's purposes, which I will be able to write now. The energy calculations were made, as the reports show, by Dr. Warren C. Thompson and Charles L. Bretschneider.

The figures will show you the characteristics of the continental shelf and the shoreline of the Gulf of Mexico, and some of the methods by which this study is being made.

Figure 1: Large-unit classification of the coasts of the Gulf of Mexico, which I made a couple of years ago.

The deltaic coastal plains [1]* extend from the Apalachicola Delta in Florida around the coast to the west and south to the steep young mountain-making coast of Tampico-Vera Cruz [3] with a narrow continental shelf and coastal plain, where the influence of the Sierra Madre Oriental is felt.

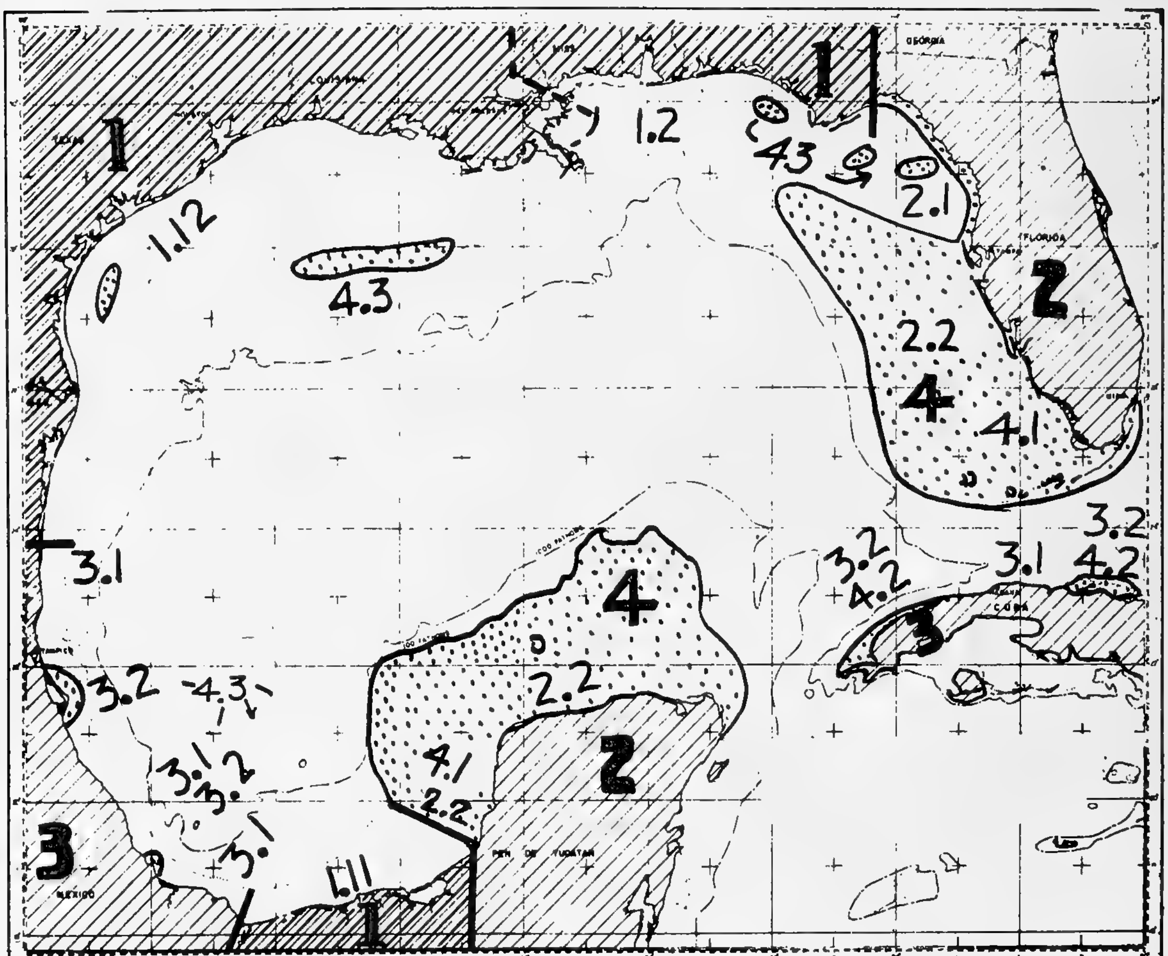

Figure 1.

*Bracketed numbers indicate zones marked on Figure 1.

I had to do some field work this summer to find out whether I should classify the section of the coast between the Mississippi and Apalachicola deltas as deltaic [1.2], but I believe I should.

There is a 200-mile delta [1.11] on the Isthmus of Tehuantepac in the rain forest area.

The two limestone peninsulas [2] of Florida and Yucatan are shown, and imposed on their shelves is what has been called a biogenous type of coast. I do not consider this a basic coastal type as far as the land is concerned, but it is a marine overlay on other basic geological units such as the drowned limestone peninsulas. We could consider the limestone itself as a product

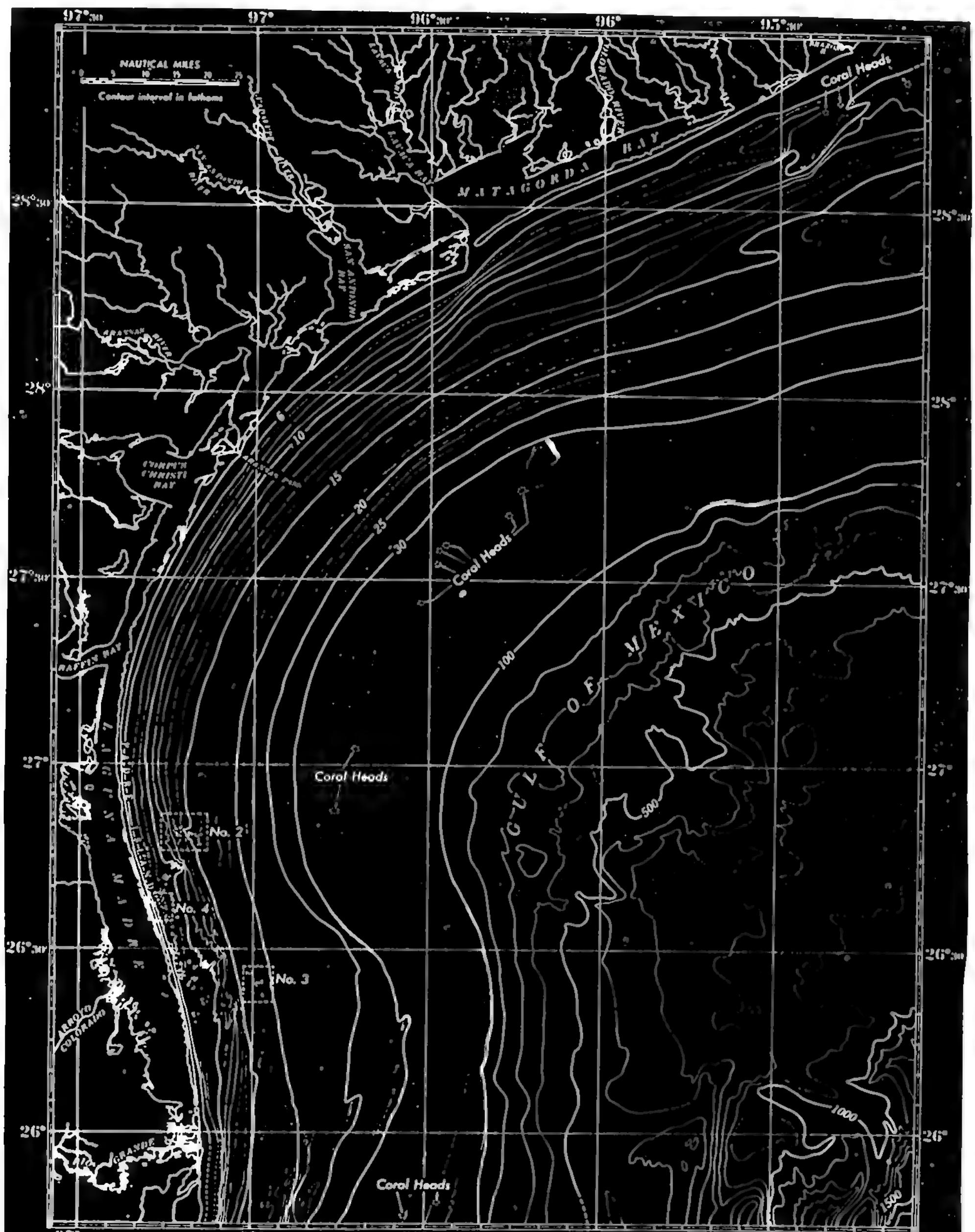

Figure 2.

of former biogenous conditions. In the tropical regions where corals and mangroves are conspicuous, the biogenous coastal condition is widespread.

The western or Gulf coast of Cuba [3], which was studied in part, is another steep young mountain-making coast, but one without a continental shelf or coastal plain. The Cuban section [3] and the Mexican sections [1 and 3] have not been included in the energy study because of lack of detailed data. I have investigated the geomorphology of these coasts and classified some of the shoreline types.

Figure 2: Map from the Coast and Geodetic Survey Journal. G. C. Mattison has given us this nice contouring of the continental shelf off Texas. You will notice the shelf comes out evenly and smoothly, and then (with a change of contour interval) curves down more steeply to the very rough continental shelf slope.

Notice the Rio Grande Delta. While it is only a small extension of the coastline of about 15 or 20 miles, there is a similar bending out of the depth lines all the way down to the considerable depth of 100 fathoms. The profiles will show that this shelf seems to be broadly down-warped.

At the north, on the Brazos-Colorado Delta, there is a widening of the shelf which continues out to 10 fathoms.

Figure 3: Profile off Corpus Christi Pass. This is a typical profile of the northwestern section of the continental shelf between deltas. At the shoreline is the short but very steep offshore slope of the barrier islands which continues out through a zone which is slightly concave, and then begins to be convex, the convexity extending down the slope of the continental shelf.

Figure 4: Profile of the Rio Grande Delta. The preceding profile between deltas is shown by the broken line. The comparison of the two profiles shows an extension of the shelf which seems to be a filled terrace. It passes landward into what seems to be a cut terrace with large

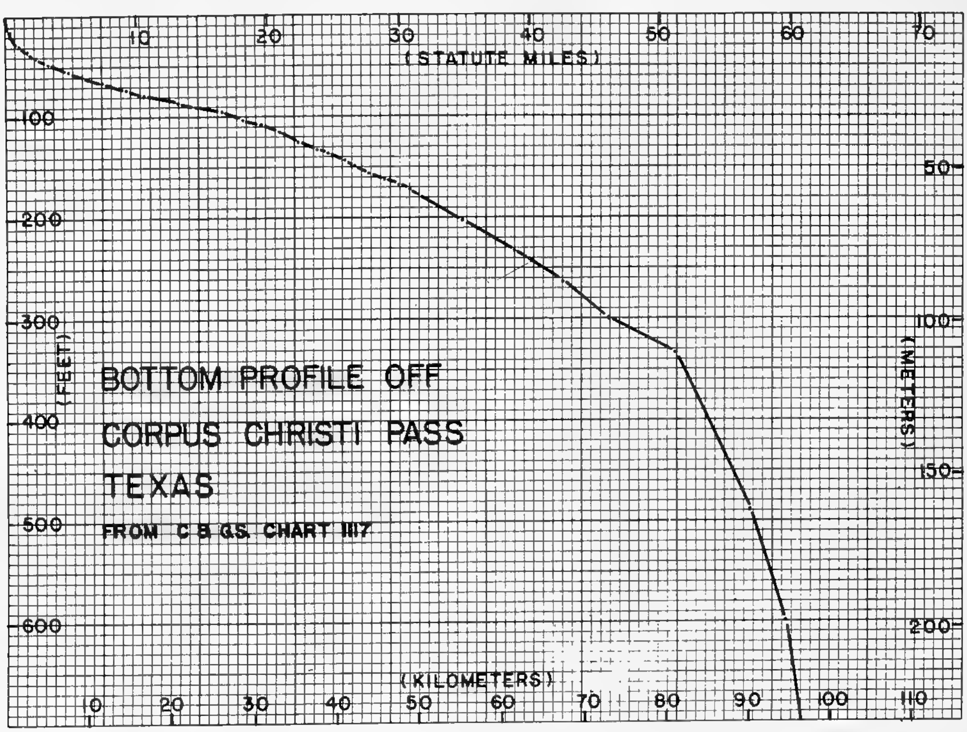

Figure 3.

bars on it. It may seem incautious to compare two particular profiles without a large number of others to check them, but I have drawn a number of others and these two are characteristic. This figure shows the typical textbook cut-terrace and filled-terrace. There is more material in the filled area than has been lost in the cut area. Deltaic deposits should account for the excess.

Figure 5:* Indicates erosion at the shoreline of the cut terrace of Fig. 4. This body of clay on a sandy beach is rare here, but I have two or three photographs of the occurrence taken by other people, although I have not seen it myself. This seems to be deltaic clay from a sub-delta of the Rio Grande which protruded into what is now the Gulf. The shoreline in this particular area has retreated. This figure shows that erosion of the delta is going on, and our deduction of a cut-terrace is warranted in actual fact.

Figure 6: Typical profile off the northwest coast of the Gulf of Mexico (Big Constance Bayou), showing again for comparison the Corpus Christi profile and a somewhat similar profile off Panama City, Florida, east of the active Mississippi Delta. The comparison shows the outbuilding that takes place where the Mississippi, Red, and subsidiary rivers enter the Gulf. The outbuilding extends eighty miles to the steep continental slope.

Figure 7: Profile off Panama City in the Panhandle of Florida, shown as the second broken line in Fig. 6. This is more or less the Corpus Christi type, with some built-up material on the shelf, but not as smooth as the Corpus Christi profile. This figure exhibits the typical sudden short descent off the sandy barrier island, and some bars or old deltaic deposits. The concave portion of the profile is about 18 miles long.

Figure 8: G. F. Jordan's published map of the new, very accurate contouring of the continental shelf slope off Florida. Note the De Soto Canyon and some lesser drains on the slope and the great scarp at the base of the slope. The shelf has no sharp edge but is broadly and smoothly bowed down. At the other side of the Gulf the contouring off the Corpus Christi and

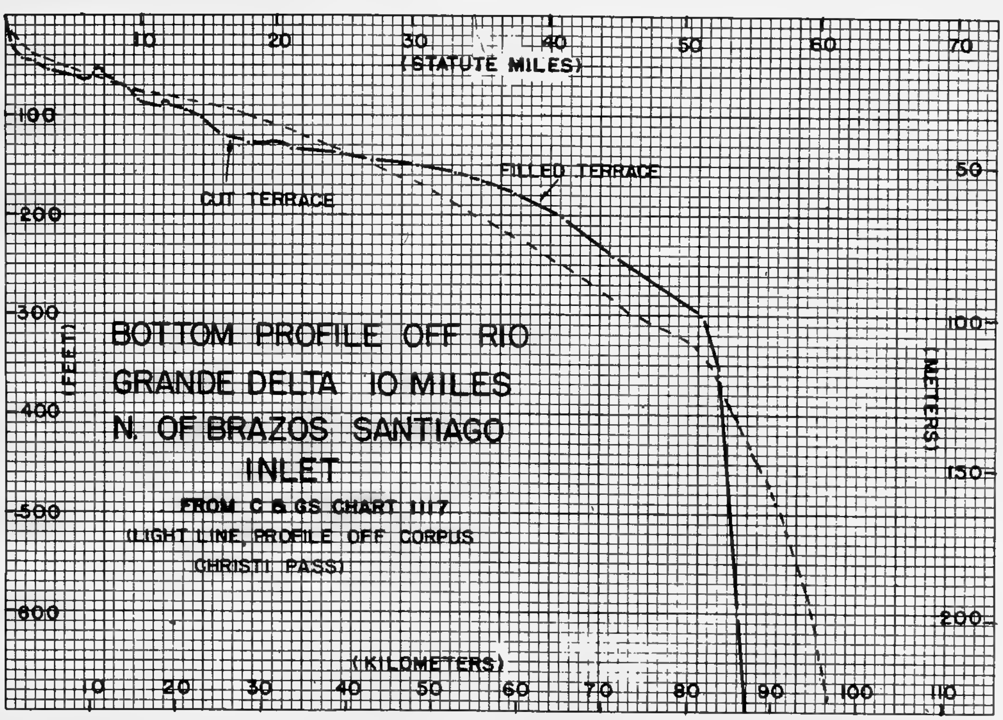

Figure 4.

*This figure was not available for publication.

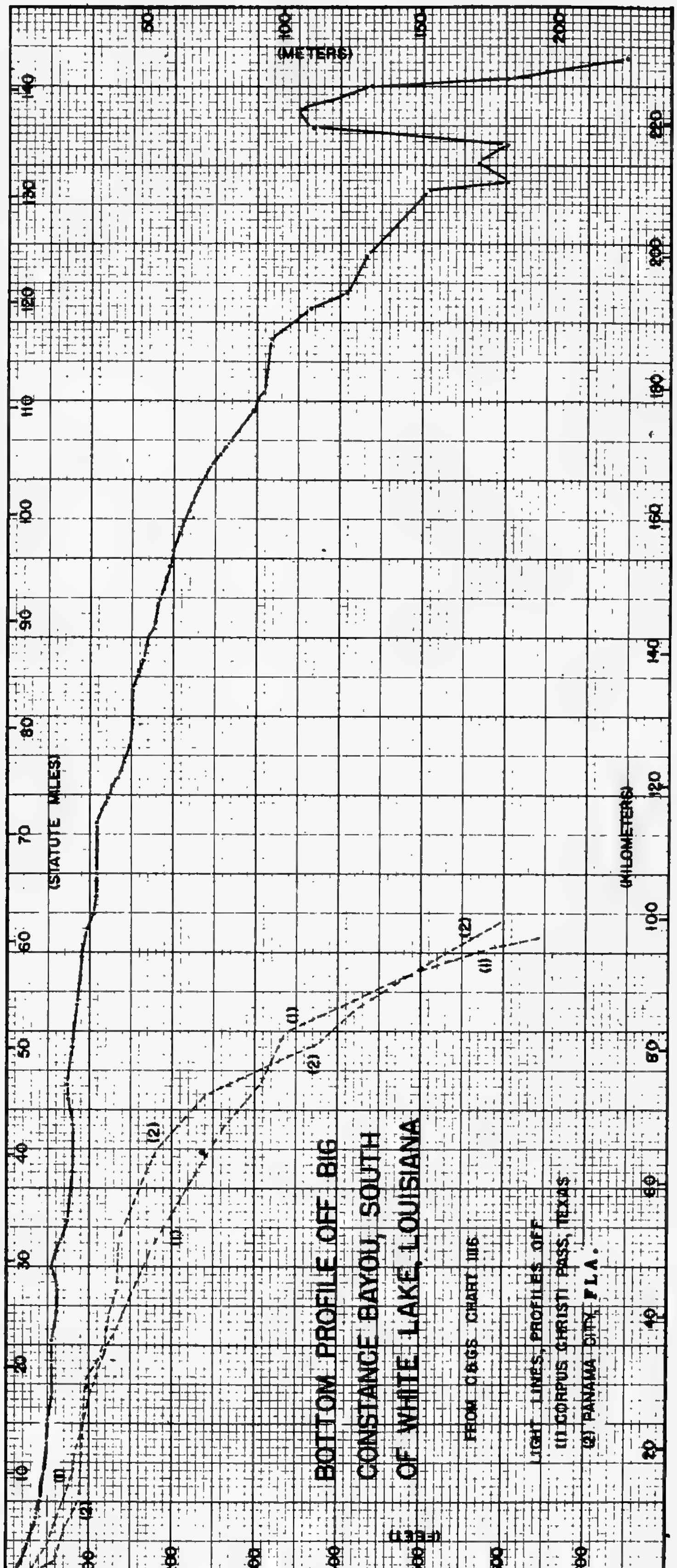
BOTTOM PROFILE OFF BIG
CONSTANCE BAYOU, SOUTH
OF WHITE LAKE, LOUISIANA
FROM C.&G.S. CHART 1116
LIGHT LINES, PROFILES OFF
(1) CORPUS CHRISTI PASS, TEXAS
(2) PANAMA CITY, FLA.
(STATUTE MILES)
(KILOMETERS)
(METERS)
(FEET)

Figure 6.

Rio Grande delta areas shows a similar type of profile, smoothly bowed down with scarps at the base. The similarity is striking: one profile is on the hard limestone shelf and the other on a deltaic shelf. This similarity has some implication as to the history of the building of the continental shelf.

It was seen that the profile from the north Gulf coast at Panama City, east of the Mississippi Delta, is also steep and abrupt like the profiles at Corpus Christi and here. These profiles show a similar characteristic of the continental shelf from west to east, regardless of the type of sediment forming it.

Figure 9: Profile off Crystal River Mouth, Florida (going south on the Gulf coast of the peninsula of Florida). This one, off Crystal River, is from the northern third of the peninsula where there is what I call a drowned karst coast and shoreline. You notice again the inshore concave section of the profile. Neither a sandy beach nor a barrier island exists here. The concavity is very low and flat, and there is not a steep jump-off just offshore as seen earlier, only a slightly modified karst plain with some elevations (bars) in the sand zone.

The land portion of the limestone plain slopes about one and one-half feet per mile. Off shore this slope is one foot to one and one-half feet per mile with the same karst pattern seen through the water as seen on land. Some fathograms show the rolling karst depressions and ridges as expected. Others to the south off the central beach-bordered sector of Florida are nearly smooth showing the karst depressions partly filled.

The sailing directions say there is not enough sediment in the karst depressions to make good anchoring. Therefore we know that the sedimentation is quite slight, as indicated also by Howard Gould's studies, but there is still much to learn about the character of this shelf and the limestone composing it.

Figure 10: Profile off Las Bocas on the western (Campeche) mangrove coast of the Yucatan Peninsula. This profile is similar to that shown for the drowned karst coast of Florida, but it has a coral platform. The small scale of the generalized chart from which the profile is

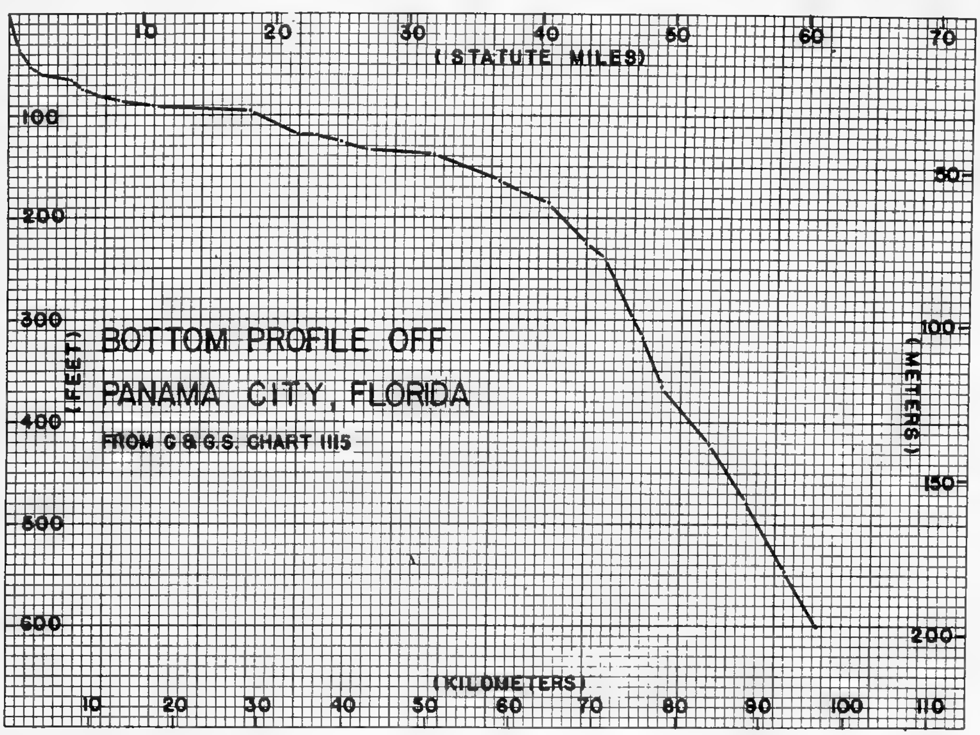

Figure 7.

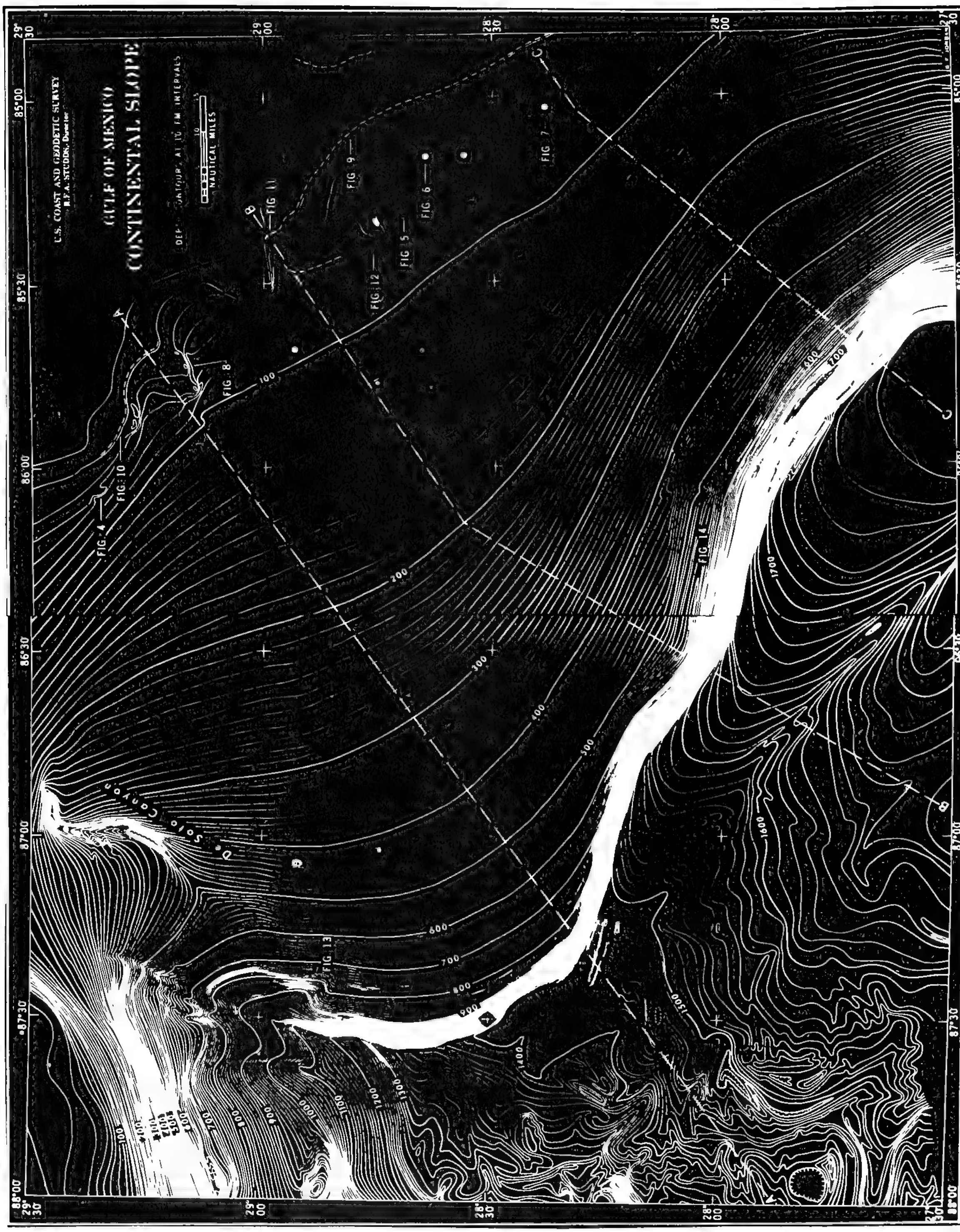
U.S. COAST AND GEODETIC SURVEY
GULF OF MEXICO
CONTINENTAL SLOPE
NAUTICAL MILES
FIG 4
FIG 5
FIG 6
FIG 7
FIG 8
FIG 9
FIG 10
FIG 11
FIG 12
FIG 13
FIG 14

Figure 8.

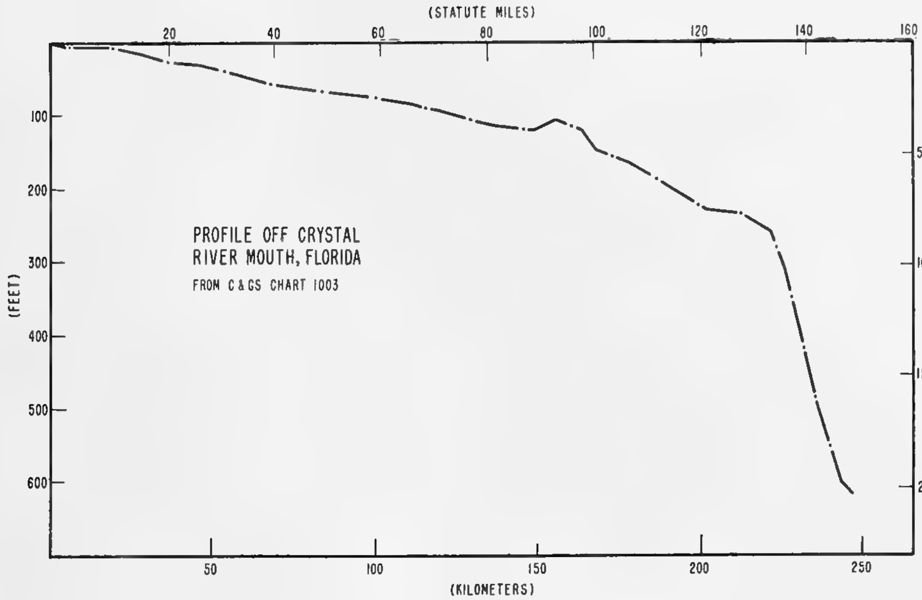

Figure 9.

made does not show the details. The coral platform has its base between 20 and 30 fathoms along the Campeche banks off the north and west shores of the peninsula. There is a build-up of 8 fathoms of material standing above the normal profile of the continental shelf, in addition to the reefs.

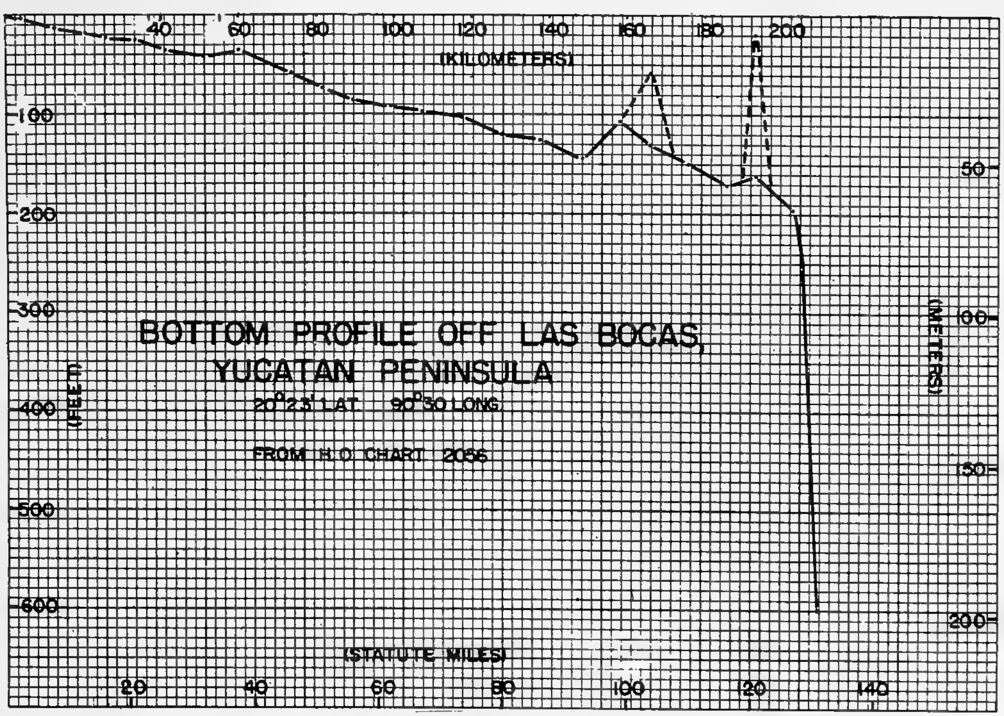

Figure 10.

Figure 11. The Three Hydrologic Regimes. We have seen a series of characteristic profiles of the continental shelf of the northern half, and a portion of the southern half of the Gulf of Mexico. We found that the profiles are concave near the shore, and that there are various obstacles farther off which stand above the projected line of that concavity. Seaward from these obstacles the profiles show a general convexity at the edge of the continental shelf. This convexity merges quickly with the steep continental slope.

Comparing the shelf profile with that of the river, which is well-known, and that of the submarine canyon, which is beginning to be known through the work of Maurice Ewing and others, I find we can make a generalization that sedimentary particles moving from the mountain top or slope to the oceanic abyss, must pass through three—possibly in some cases only two—hydrologic regimes.

First the particle comes down the river, descending the steeply concave slope of the upper river profile, very much exaggerated here; then the middle and lower courses through the plain; then the delta.

The delta extends into the Gulf and overlaps the profile of the next regime, that of the continental shelf. This drawing is approximately to scale so that the shelf is shown very short. (The shelf profile is shown enlarged on the next figure.) At the outer margin of the shelf is a convexity which usually occurs except in badly deformed shelves. Clay is found here. It is in this convex portion that you find the heads of the average type of submarine canyon.

Last month Kuenen presented a classification of submarine canyons. He calls his common type the New England type. Study of the New England type of canyon shows the head to lie commonly just at the inner side of the outer shelf convexity, where it joins the nearly horizontal section or its built-up portions.

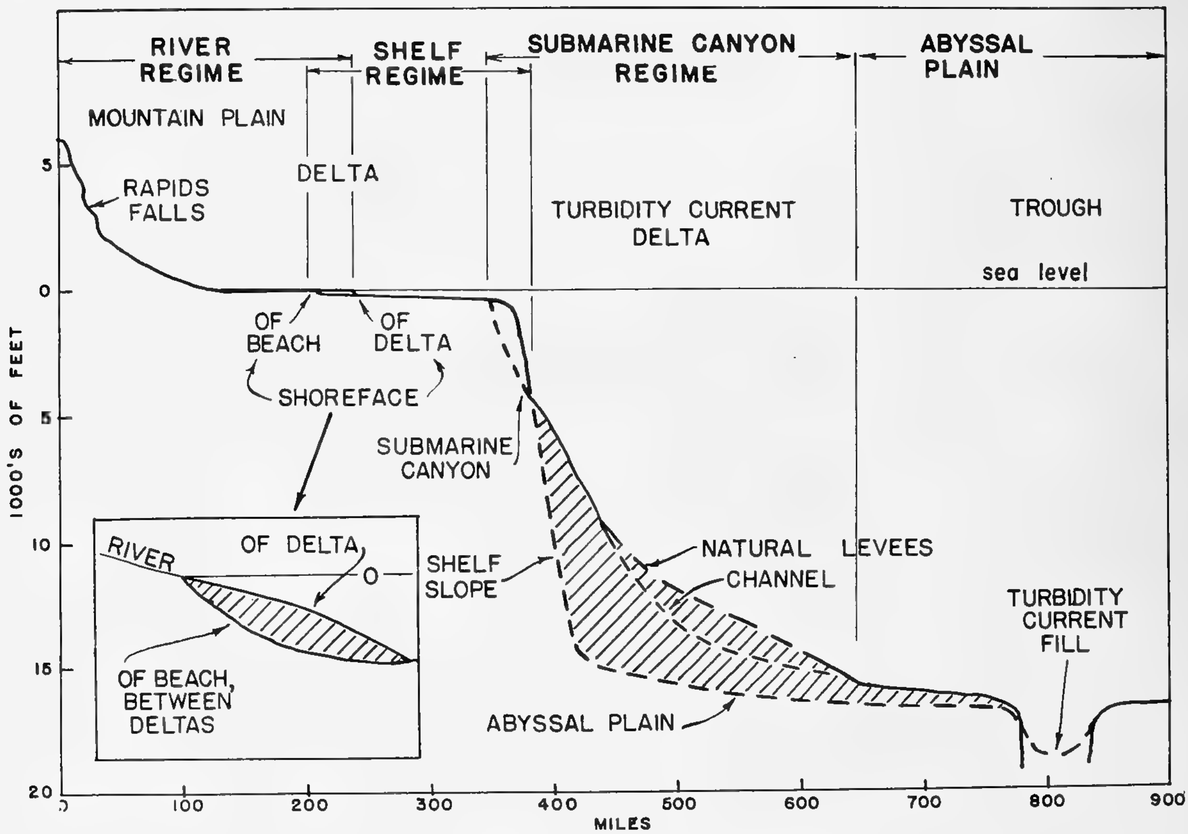

Figure 11. The three hydrologic regimes of sediment transport and erosion, true proportions diagrammatically shown.

If one were to analyze the few contour maps we have of the submarine canyons, one would find their upper parts cut into the shelf and then emerge as channels in deltas. The shaded portion of the figure indicates the built-up section of the delta that becomes an apron, apparently a very widely dispersed, widely extended, thin layer of depositional material extending beyond the definite delta. The delta is at the foot of the submarine canyon, and the apron is where the turbidity currents flow out on the abyssal plain. Maurice Ewing's work of last year in the Atlantic shows that the turbidity flows which come down from the northeastern coast of North America enter the great western Atlantic Canyon from Greenland and flow down a tremendous distance to the abyssal plain and into the deep off Puerto Rico. Figure 11 shows, diagrammatically, the same situation with the apron reaching a trough which might be receiving some of the turbidity-current material.

Ewing showed that along the great Atlantic canyon the landward side of the abyssal plain was higher than the other side. Justification of similar conditions shown here is found in the contouring of the bottom of the Gulf of Mexico.

Computations by C. L. Bretschneider, V. J. Henry, my son William, and myself indicate the astonishing volume of 19,000 cubic miles for the deep delta at the foot of the Mississippi canyon. In computing the volume of the delta, I assumed that the continental shelf originally had the steep slope which is shown at the north (Fig. 7) and at the west (Fig. 3) and that the delta was built on such a shelf and with a nearly flat Gulf floor. If we assume major irregularities of the floor and projections of the slope, we may subtract a third of the volume and still have approximately 12,000 to 13,000 cubic miles of material.

I did not know that this shoreline study was going to involve consideration of the bottom of the Gulf, but from the shoreline to the abyss there is a continuity of events and processes. This is itself a major scientific result of this research project.

You will notice on Fig. 11 that the three different regimes each have a concave profile. At the lower ends of the upper two profiles where the energy is about spent, the curves become convex in the terminal dumps. This low-energy convexity is an overlap and an interfingering with the next lower regime.

A basic similarity in these three profiles is the drop in elevation (with the resulting gravitational difference) between the ends of each profile to provide energy in a moving body of water. Material is transported down the river. There must be transport of material across the shelf, although the exact method is not known to me. Water coming in from the land must get off the shelf. Water transported landward with the waves must also get off the shelf. Therefore, there must be a movement of water across the continental shelf to the oceanic basin, and this movement must effect the transportation of material. You find the finest material, clay, commonly building up the terminal dump of the shelf in a zone of spent energy. The energy is mostly confined to a thin zone at the surface. This fine land-derived clay has been transported across the shelf in suspension in the water which we have deduced must somehow flow outward off the shelf. Whatever movement there may be at the surface of the shelf in deep water remains to be discovered.

Figure 12: Diagrammatic bottom profile of continental shelf illustrating some of my terminology. I extend the shoreface out somewhat farther than some writers, and place the seaward edge at the point of rapid change in rate of concavity, not merely at the edge of the beach or intertidal zone. Where I have data, the shoreface of a sandy barrier island seems to extend to the bottom of the sand structure.

The ramp is a gently sloping surface, slightly concave, and asymptotic to the horizontal. In this figure a broad irregular submerged deltaic mass is shown rising from the plane of the ramp. It is being smoothed in its Gulfward parts and eroded and graded into the shoreface-ramp profile near shore. Where the submerged deltaic deposits and other obstructions have been removed, as they have in a few places, the ramp continues to join the terminal convexity, shown by the extrapolated broken line. I have applied the word camber meaning convexity, to the terminal convexity of the shelf. Some people call the zone where the curvature reverses from concave to convex the "shelf break," others pick any point where the curvature is changing rapidly near the shelf edge; some consider a terrace or some kind of slope irregularity as the "break." If we are to use such a term, it should be defined.

I use the terms "camber," "ramp," and "shoreface" for the three parts of the profile and do not attempt to fix a "shelf break." Neither do I analyze the topography of the shelf slope.

You will notice there is an overlap of the concave river profile on the continental shelf, and overlap of the camber on the submarine canyon profile. Each high-energy zone begins in the low-energy section of the preceding profile.

Figure 13: Map of wave energy and shelf conditions showing energy data computed from wind data for six coastal stations. The energy of wave motion in the wind-wave is computed in terms of horsepower-days per foot of crest advance and per foot of wave crest length for onshore winds on a deep-water basis. The figures were developed by Dr. Warren C. Thompson, now of the Navy Post Graduate School of Monterey, California. He used regional wind data taken at the coastal Weather Bureau Stations to compute the energy from each onshore wind direction using a series of formulas and curves he developed. These values are shown in his report in an energy wind-rose for each station. These shore data are considered to be applicable to the adjacent edge of the continental shelf. The energy for the deep-water wave applies at that point.

At first we worked on the idea that it was mainly the onshore wind-wave movement which was significant. When we thought about it more, we saw that offshore winds must also do appreciable work on the continental shelf. As the fetch increases, the wind strength and wave development increase gradually, and there is significant wave attack on the bottom.

Charles L. Bretschneider, who has developed formulas and curves for computing bottom-friction losses in wave motion, helped on this problem. He computed the total wave energy for winds from all directions for one of the stations used by Thompson. His computation for Galveston show 654 horsepower-days as a deep-water gross-energy figure as compared with 346 for onshore waves.

Figure 14: Spectrum of Bretschneider's wave-energy values along a profile of the shelf off the Brazos delta and river mouth near Galveston. Energy along the bottom slowly decreases landward up the steep shelf slope. Only 5% is "lost" in motion across the remote, deep camber section of the continental shelf. A total of 20% is "lost" on reaching a depth of 100 feet. Approximately 75% of the energy reaches the outer edge of the ramp after crossing the broad but low deltaic elevation which has absorbed some of the energy. However, in speaking of "lost" energy, we are considering also changes in energy due to reduction in fetch of offshore winds. On this nearly horizontal ramp, eight or ten miles long, only 10% of the energy is "lost." Thus, in this example, 64% of the energy is left to be expended on the shoreface, the surface of the steep, sandy barrier island with its offshore bar zone. As we will see, this flat ramp is a low-energy zone.

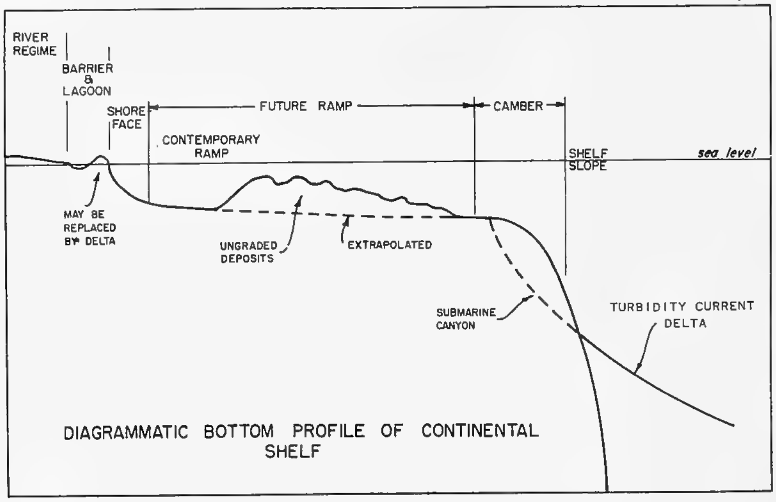

Figure 12.

We would like eventually to develop such energy spectra for all the characteristic profiles of the continental shelf. We would like to do this on a more detailed basis, because all these profiles have been drawn from the navigation charts. We realize that the details will be much more interesting when we are able to contour the smooth-sheets. However, it will take a great many man-hours to contour many smooth-sheets, and the project, as set up, does not provide for that much work.

If, somehow, we can get that type of work done, the study will be very much improved. We think there will possibly be a correlation between the sediments, the minor bathymetry of the submerged deltaic plain, and groups of the bottom living organisms. This is a fertile field for investigation from the scientific standpoint, with the hope that something will result in the applied phase.* We have a project planned for which we are going to try to get support, to enable a biologist to study those details in an area where we are now getting samples, fathograms, and other information in another Navy project.

With the data on energy that we now have and our knowledge of the shorelines, we made this diagram map (Fig. 13) of the Gulf. Starting in 1951, I made a typical geomorphic study of the shorelines of the Gulf of Mexico and also a series of maps showing the different types. Fifty-eight types were found; nine of these were new. It was necessary to enlarge the genetic-geomorphic classification tables to accommodate the new types and listings.

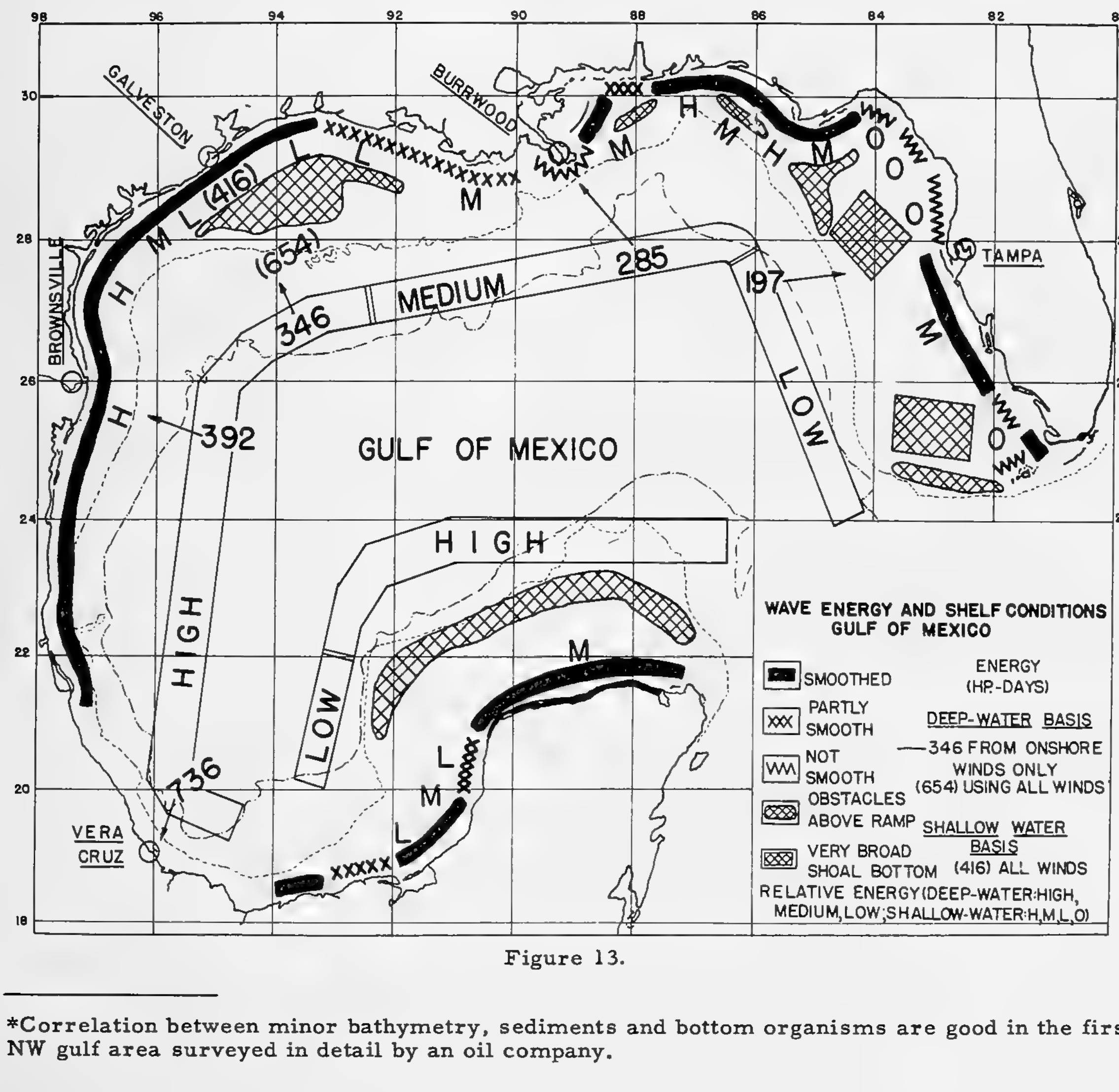

Figure 13.

*Correlation between minor bathymetry, sediments and bottom organisms are good in the first NW gulf area surveyed in detail by an oil company.

Most of the shoreline types of the Gulf belong to the inner lagoons and bays. However, we are studying at present only the marine shoreline. I find that the significant factor for the outer coast is the degree of smoothing.

Smoothing is significant from the geological as well as the energy relations standpoint. It is very significant with respect to landings and all kinds of shore operations. Smoothing is primarily accomplished by wave energy, which grades the shoreline and shelf bottoms. It is well known that progressive modification of the shoreline by the ocean brings about simplification and smoothing. A smooth coast should be considered in a mature condition.

The heavy black lines in Fig. 13 indicate the coasts which are well smoothed. On a drowned river-valley coast, numerous in this area, shorelines may be smoothed by sandy barrier islands built across the river mouths. Thus a smooth coast is found wherever such barrier islands are formed.

The barrier islands are built of sand. Proved sources of this sand are dominantly river and bay sediment in Texas, southwestern Louisiana and central Florida, bottom sands in the Chandeleur Islands of Louisiana, and shell sand on the north shore of the Yucatan peninsula. Pocket beaches on the west coast of this peninsula have limestone cobble eroded from upfaulted limestone hills. The limestone coast of the Champoton-Campeche fault-block is smoothed by erosion of the rock and building of pocket beaches.

In the Gulf all the smoothed coasts show high to medium energy inshore. The completely unmodified, unsmoothed shorelines are where the energy is very low. Along the northern third of the Florida peninsula there are numerous areas, each several miles long, having almost completely unsmoothed shorelines. These unsmoothed shores are found on the drowned karst with practically zero energy. There we find innumerable small peninsulas and islets with small bays and channels. The low elevations are occupied by palms and other trees. There are archipelagoes of islets extending four or five miles from the shoreline. I described this type of coast in a manuscript which will be published in about a year (Communications of IV Congress, INQUA, Rome and Pisa, Italy).

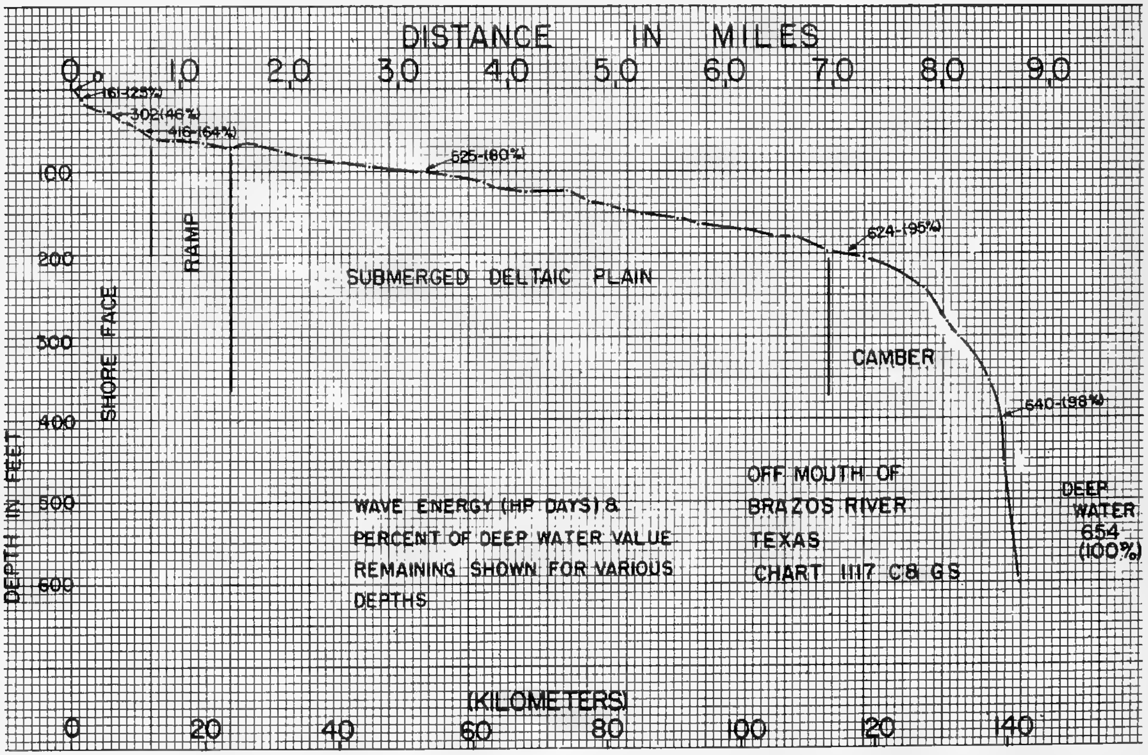

Figure 14.

At the southern end of Florida there is a mangrove barrier ridge with an irregular lagoon behind it. The mangrove growth is a completely unsmoothed archipelago, partially protected by Cape Romano, a barrier peninsula which is partly smoothed by hurricane erosion where the coast is entirely open. This is a low- to zero-energy coast.

On the northwestern part of the Yucatan peninsula the mangrove swamp fills the karst re-entrants on a slightly steeper karst plain, making a somewhat smoother coast. All the marine mangrove swamp shoreline is cross-channeled by tidal scour.

Another example of a completely unsmoothed coastal feature is the crow-foot delta of the Mississippi, which the wave energy has not been able to reduce. Although the sides of the "leg" may have somewhat smooth shorelines, the "feet" (passes) are strongly protuberant features.

On the drowned karst coast of Florida there are areas where a low-lying coastal strip was filled in by sand during a previous high sea level. This produced a low sandy plain that probably originally had a smoother shoreline than it has today. The coast has been abundantly cross-channeled by tidal scour in the sand, presumably between buried karst elevations. This is considered a zero energy coast and the longshore currents, longshore sediment drift, and wave attack have been too weak to smooth the coast. It has been made irregular by tidal scour.

A moderately smoothed coast is found in Louisiana west of the delta. The coast is lobate. Bay barriers of sand or oyster reefs smooth the shoreline but are not well aligned. In places they are retreating rapidly due to decreasing sand supply in the longshore drift accompanying a shift of run-off volume from the Mississippi to the Atchafalaya River. Atchafalaya Bay has no longshore sand drift, and, in consequence, an irregular barrier oyster reef replaces the usual smooth bay barrier of sand.

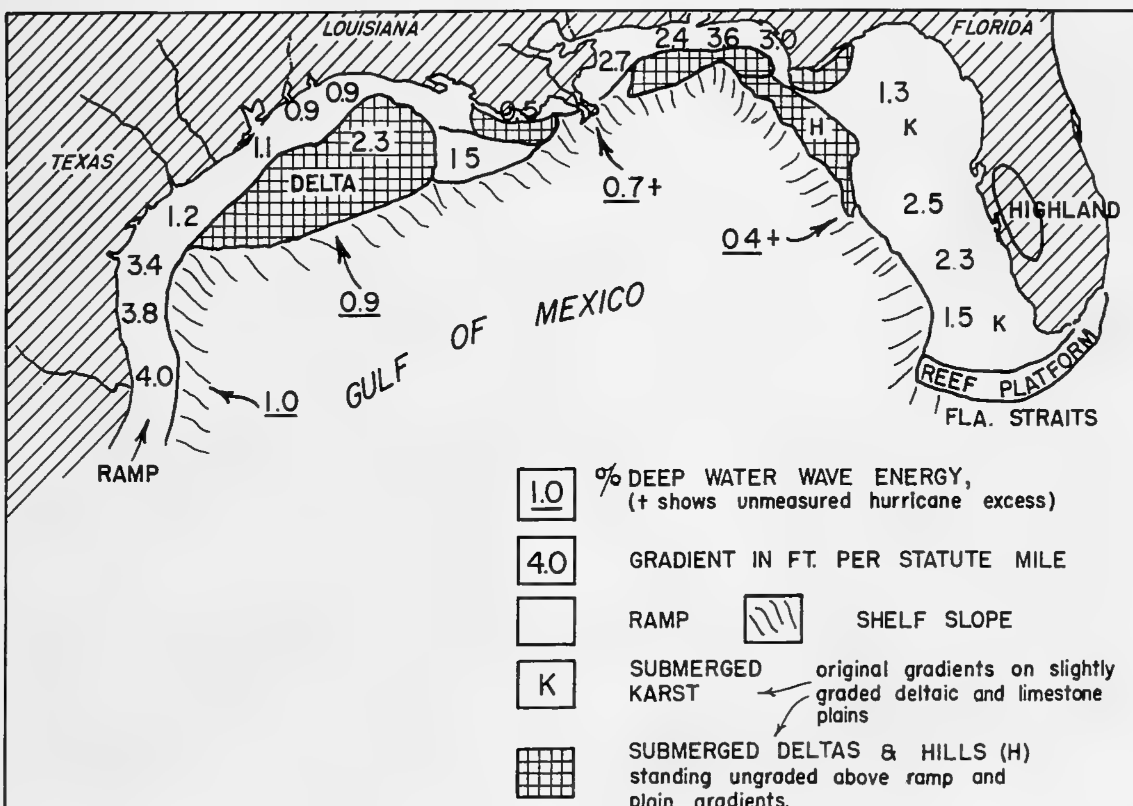

Figure 15. Relation of energy, obstacles, original gradients, and lithology of bottom to gradients of ramp and submerged land surfaces on continental shelf.

The north shore of Yucatan is smoothed by beaches of shell sand and barrier islands which, however, are not well aligned, probably due to irregularities of the limestone. The mapping is poor and only a few aerial photographs have been examined.

Before I had any numerical figures for energy, I considered first, the two wind systems of the Gulf, the southeast trades and the cold fronts of winter; and second, the slopes of the ramps or hard-rock shelf surfaces (Fig. 15). The trades (a) blow at right angles against the west coast of the Gulf, delivering their full energy, (b) blow alongshore or diagonally at the north coast, giving less energy there—I call it medium energy, and (c) blow offshore at the east, which I call a low-energy coast with zero energy where the hard-rock shelf is both broad and very shoal.

The cold fronts come from the north. Their winds, and the induced wave fronts, blow alongshore at the east and west, and do not do much work. The northern Yucatan shoreline lies across their path, and these "northers" produce high energy at the edge of the shelf and medium energy at the shore. The very high energy figure for Vera Cruz shown on Fig. 13 (736 horse-power-days) is due to the long fetch of the northers and the work done by cold air on a warm ocean. Apparently the north Yucatan coast must have some similar figure, perhaps three-fourths at least of the Vera Cruz value. This would account for that fairly high energy north-facing coast. The appreciable slope of the bottom and the considerable distance off shore and depth (20 fathoms) of the coral platform allow a fairly large percent of the energy ("medium net energy") to reach the shore.

On the low-energy coast, wave activity is low and breakers absent. Along this type of coast on the northwest Florida peninsula the U. S. Army Engineers, much to their surprise, could work far out on the shelf in small 2-spud coring boats even in winds up to 25 or 30 miles per hour. The same thing is true behind the barrier reef along the Florida Keys. There is only choppy water, even with high winds.

These relative energy concepts were applied before we had any numerical energy values. Now we have the Thompson figures for the wind-wave energy of onshore winds on a deep water basis. You will see that in the north half of the Gulf the values range from about 400 at the west to 200 at the extreme east where the broad shallow shelf absorbs nearly all the energy of the onshore wave systems.

In the energy study there are two situations: the gross-energy values at the shelf edge determined either by a relative scale, or numerically from the regional winds on the deep water basis; and the net-energy values of waves that reach the shallow water zones near the shoreline. The inshore net energy largely determines the individual type of modification of the shoreline, but the total or gross values are involved in shaping the continental shelf. Actually there is a continuous energy spectrum and a connected series of bottom conditions across the shelf.

I have drawn on the maps of Figs. 13 and 15 the obstacles which stand above the ideal continuous smooth profile of the ramp and camber. These obstacles absorb more energy than would be absorbed by a smoothly graded shelf. On relatively flat ramp slopes there is a large energy loss by bottom friction, while on steeper slopes there is only a small frictional loss.

Off the Mississippi-Red-Brazos deltaic zone there is a great submerged deltaic plain which is quite rough, rising above the ramp-camber curve. Off Yucatan a coral platform standing above the drowned land surface has gross features which probably have not been very much modified by the waves. The two shelf regions are basically similar, although of different origin, lithology, and energy relations. Each has a ramp-camber plain encumbered by an unreduced elevation extending to the camber.

Along the north Gulf coast (Fig. 15) the energy is low and the ramp is relatively flat behind an obstacle. Where there is no obstacle, the energy is greater and the ramp is steeper.

We are now ready to understand and interpret the maps of the continental shelf. Figures 16, 17, and 18 show the first mapping of the physical environments of the continental shelf of the Gulf of Mexico that I know, other than sediment maps. The environments mapped are

properly dynamic environments defined by topographic (bathymetric), physical, and geological data. Using the slopes of the continental shelf taken from profile studies, the outlines of the submerged deltaic plains, reef platforms, and other obstacles, I have drawn major longitudinal zones. The transverse energy zones are not shown on these maps but have been indicated (without boundary lines) on Fig. 13.

The shoreface is the narrow belt between the ramp and the shoreline. I have determined the height of the shoreface roughly at different points. The ramp zone passes almost entirely across the front of the deltaic plains. In places there is an inner and outer ramp. New ramps are being cut at the shoreline on very recently submerged deltaic masses, with the older, more prominent ramp on the offshore slope. Apparently there must be breakers along the outer submerged edges of deltaic shoals with a shoreface where the edge of the shoal is less than about 12 feet deep. I am sure that in storms there would be a line of breakers in such places, and we have indicated the outer ramp to show that this is the case, as on shoals off Atchafalaya Bay. The camber zone is shown along the shoulder of the deltaic north shelf but not on the west and east shelves in the broad, supposedly down-warped areas off Florida and Texas.

In regard to the "down-warp" of the western shelf, zones of strong folding buckle the Cretaceous and early Tertiary strata only 60 miles inland. Off shore from the Rio Grande delta there are submerged mountains shown by the war-time soundings. One mountain top stands about 3,800 feet above the adjacent bottom. Its flanks slope several hundred feet per mile. Thus, this western shelf lies between areas of considerable diastrophism and is apparently a down-warped shelf as its broadly bowed profile suggests.

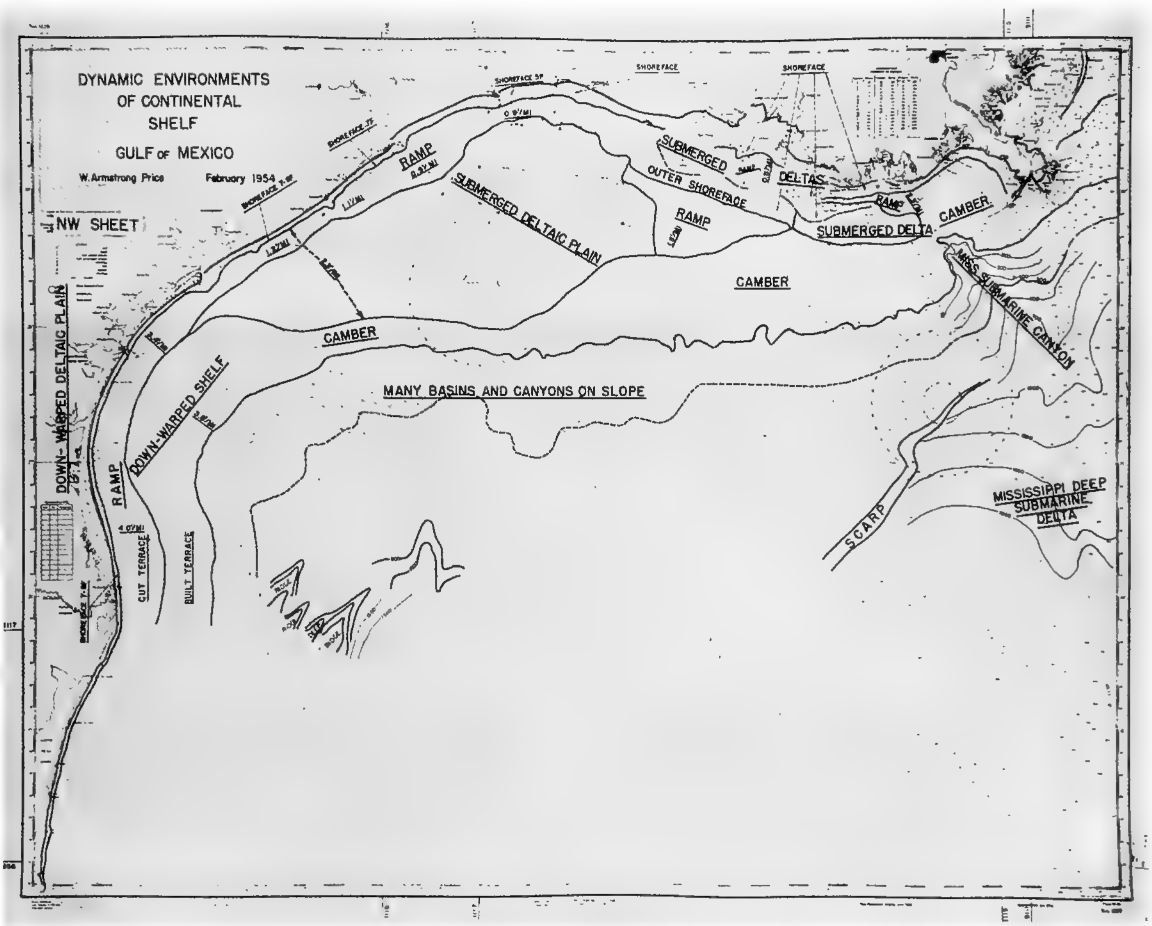

Figure 16.

Figure 17: Companion chart for the eastern half of the Gulf. The same longitudinal zones are present. We have discussed them in connection with the diagram maps of the Gulf (Figs. 13 and 15). The submerged karst plain of Florida is slightly modified by recent deposition in the karst depression and by erosion which is partly organic.

As discovered by Howard Gould in his dredging, the shelf of the beach-bordered central Florida coast is covered by a crust or spongy zone, perhaps a foot or two thick in places, formed by the calcareous tests of all kinds of organisms. Gould hoped to obtain samples of the rock but could get only tiny chips of black limestone which were dredged up with large amounts of the spongy crust.

The Florida Keys stand on a reef platform like that on the Campeche Banks off Yucatan.

Off western Florida, in the low-energy zones, are a range of limestone hills, low ridges, and dome-shaped mounds. Gould concludes from samples that the mounds and low south-pointing ridges along the 30-40 fathom contours are probably algal reefs. Rock ledges are reported by divers. The ledges overhand slightly at the east.

Much narrower and much steeper submerged deltaic bodies than those in the west are found east of the Mississippi delta. These eastern bodies are less effective as energy reducing obstacles than those to the west. The navigation charts are not detailed enough for a satisfactory study of the surfaces of these obstacles. They seem to be consistently cross-gullied

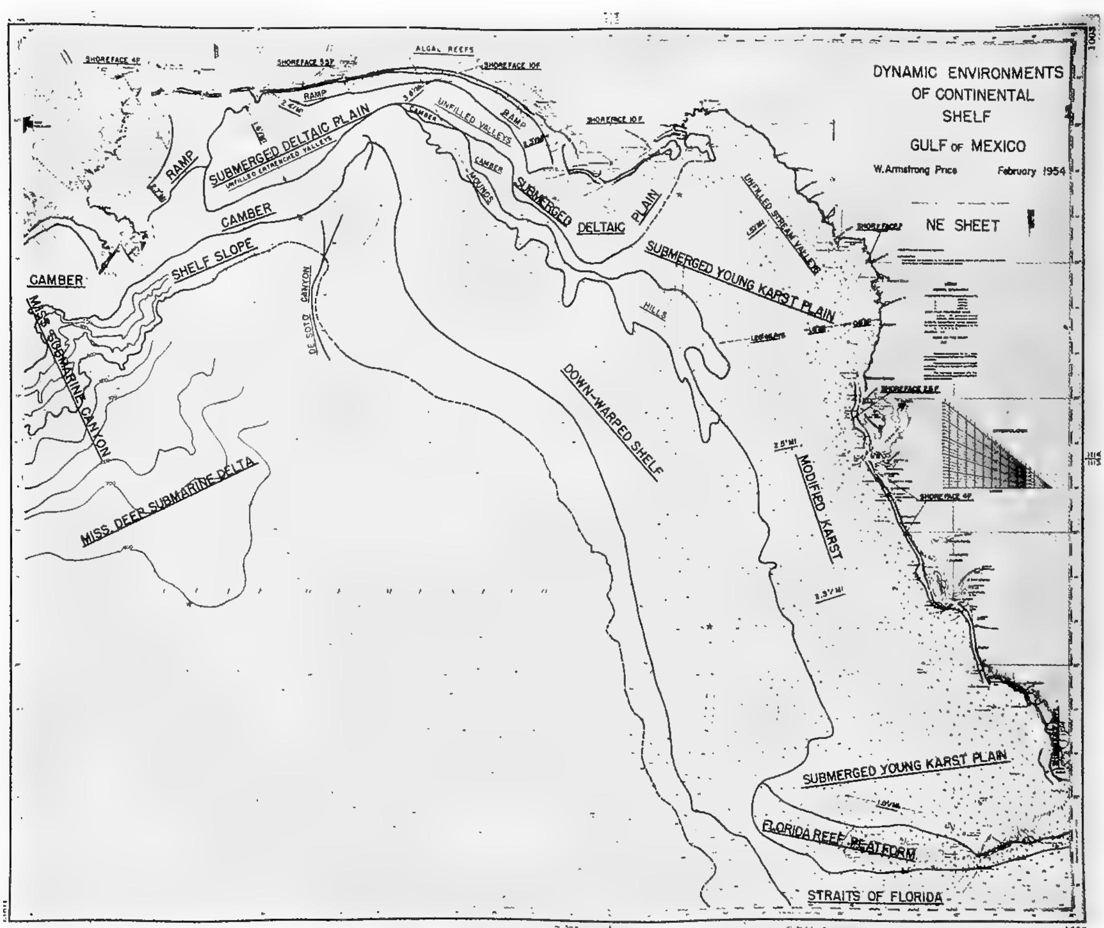

Figure 17.

as if transversely entrenched stream valleys were cut during the last lowering of sea level. The gullies have not been filled by sedimentation, nor have their divides been removed by erosion. Some of these gullies are definitely shown by the soundings, and others inferred from insufficient data.

The floor at the upper end of the Mississippi submarine canyon is about 450 feet below sea-level, which Fisk estimates to be the amount of the last great lowering of the sea. The contours on Fig. 17 from U.S.C. & G.S. Chart 1003 show the deep delta of the Mississippi canyon better than the older charts. The top seems to be about at 600 fathoms and the base at 2,000 fathoms. The fan extends out and down to meet the Yucatan shelf and the mouth of the straits of Florida. Its front is some 300 miles wide.

Figure 18: The Yucatan area. The shoreface is 18 feet high, which is fairly low in comparison with those of 45 to 50 feet high common on most sandy coasts. The mangrove coast is merely sketched in with only the entrances to the numerous tidal channels shown in a rough way.

The submerged karst plain at the north slopes about two feet per mile. On the low-energy coast at the west it slopes 1.3 to 1.9 feet per mile. The few elevations available on land on the north coast indicate a slope of three feet per mile to the north, suggesting that the offshore slope may be a partly built-up slope, rather than an erosion slope.

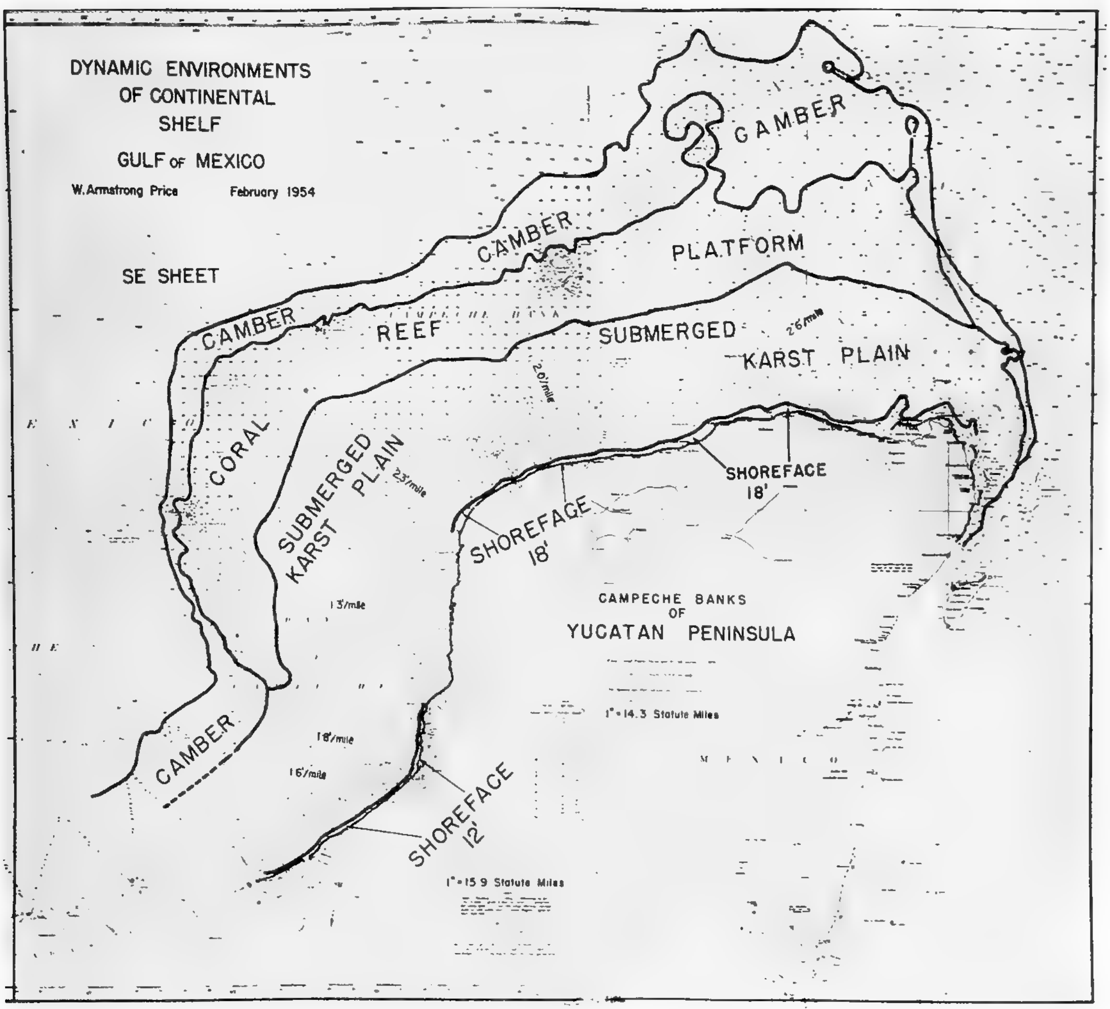

Figure 18.

By use of the concepts and data described in this talk I am able now to make some generalizations as to the energy distribution in the Gulf of Mexico, its effects on the shoreline and on the shallow part of the continental shelf. I hope in the next few months to produce a correlation table showing all these features, and to add a number of other items of practical value. Perhaps additional maps will be used. By such means we hope to correlate a great many specific offshore conditions with shoreline types.

SOUTHEASTERN LOUISIANA MARSHLANDS

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The area under consideration, the easternmost Louisiana marshlands, is outlined on Fig. 1. It is one of five areas into which the Louisiana coastal marshlands project has been divided. The western part is low marsh, broken by many lakes, bayous, and a few natural levee ridges. To the east are ten to fifteen miles of open water of Chandeleur and Breton Sounds bounded on their seaward side by the low, discontinuous, sandy Chandeleur Islands.

The area is a former subdelta of the Mississippi River and is now abandoned. Aided by subsidence and eastward tilt, land is retreating before the attack of the sea.

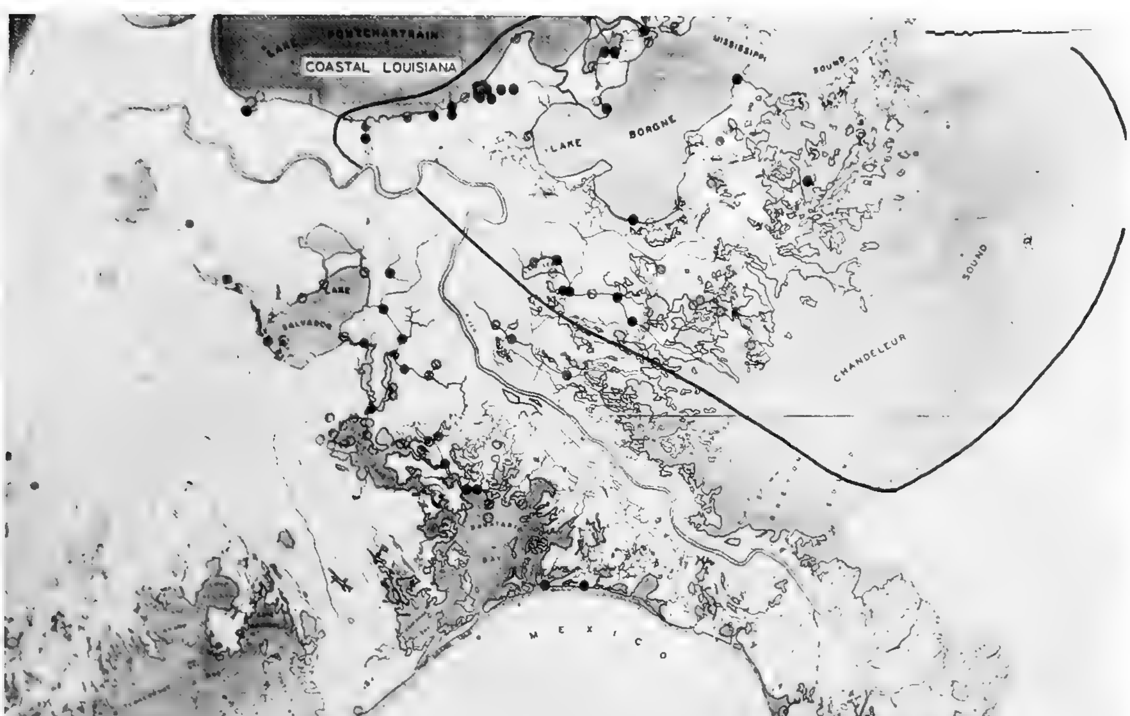

Figure 1.

TRAFFICABLE UNITS

Natural levees are the dominant topographic feature of the marshland and form the only continuous high ground. The levees radiate in a branching pattern from a focal point at New Orleans. Levee heights near New Orleans are about ten feet, but gradually diminish seaward as the levees dip beneath marsh level. Levee widths reach one and one-quarter miles on upper parts of the distributaries and gradually narrow toward downstream regions. Under natural conditions vegetation is very dense, mainly live oak and various kinds of underbrush. Natural levees are composed of silty clay and silt, and ordinarily have a high moisture content because the water table is close to the surface. The upper portion is usually oxidized, and reducing conditions prevail below. Dry levees are excellent trafficable units; however, after rain they become sticky, and ordinary vehicles are easily bogged. The effective trafficable limits of levees are always outlined either by trees or agricultural areas, which allow easy determination of this boundary on aerial photographs.

An ideal cross section of the sedimentary sequency associated with natural levees is presented in Fig. 2. The basal layer is marine sand antedating delta encroachment onto the area. Overlying this are pro-delta clays which are fine, stream-carried sediments deposited in advance of distributary mouths. River bar material rests on the pro-delta clays. Bar sediment is deposited around distributary mouths, as the stream velocity is checked by waters of the Gulf of Mexico. Fine, silty clays and clays are deposited concomitantly with bar sediment in interdistributary areas and lense into bar material. Above this are the natural levees. Levee silts and clays take the shape of a double wedge, thickest near the stream channel and thinning into the flanking marsh or lake deposits. Channels of abandoned distributaries are located between the natural levees. The basal portion of channels typically contains sands and silts, and the upper portion is filled with fine clays and vegetation. A tidal channel frequently occupies the remnant distributary channel.

Stranded beach ridges, or cheniers, are secondary trafficable units in this area. In the western part of the State they are better developed, and owing to the lack of natural levees, they are the only means of land travel in the marsh.

Cheniers of this eastern area are largely buried under marsh, but are continuous under marsh between outcrop areas. These features nearly always form a linear pattern. Their

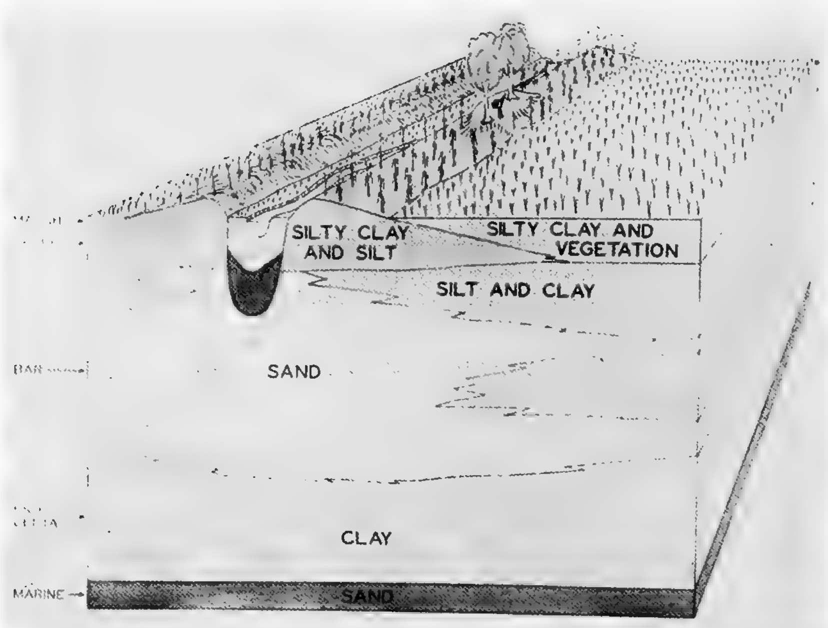

Figure 2. Ideal cross section of natural levee.

maximum height is about 15 feet, and their bases extend twenty or thirty feet below sea level. Width of the largest cheniers, most of which are buried under marsh, is about two miles. Vegetation is chiefly slash pine, live oak, and palmetto, and underbrush is thick, but does not approach the density found on natural levees.

The cross-sectional appearance of a chenier is shown in Fig. 3. It is a sand wedge partly buried under marsh and mudflat deposits, here shown resting on lake and bay deposits underlain by compact Pleistocene material.

Being thick lenses of sand, cheniers are excellent trafficable units. They support weight better than levees, and because they are porous, are as easily traversed during wet weather as during dry weather.

Present sand beaches are confined to Breton and Chandeleur Islands, a chain of islands about fifty miles long and one mile wide. The average height of the islands is about five feet, although some sand dunes rise to fifteen feet. Beaches are found only on the seaward side of the islands. The Sound side is black mangrove swamp. Beaches rest on buried swamp which they override as they move inland, and beach thickness approximates elevation. The trafficable value of beaches is similar to that of cheniers except that, because the beaches are not as thick, they will not support as much weight. Along the inner margin of Chandeleur and Breton Sounds are many small shell beaches, but they are too discontinuous to have any appreciable trafficability value.

One other marshland feature needs to be considered—the marsh itself. Marsh composes over 95% of all land south of the Pleistocene terrace. Its elevation varies from about sea level to one or two feet. Marsh vegetation consists of various grasses, rushes, and sedges, which are normally higher and thicker in fresh water than in salt water marsh. Fresh water marsh is confined to more inland areas, and is composed of highly organic clay, silt, and vegetation. Silt is deposited on the outer marshes when storm tides sweep over them.

The section in marsh areas is identified on the left margin of Fig. 2. Typically, there are 20 to 25 feet of soft organic clay resting on river bar material. In many places this organic material is so soft that a pipe can be pushed into it by hand until the hard bar materials are encountered. This is in sharp contrast to levee materials which are very compact and "tough."

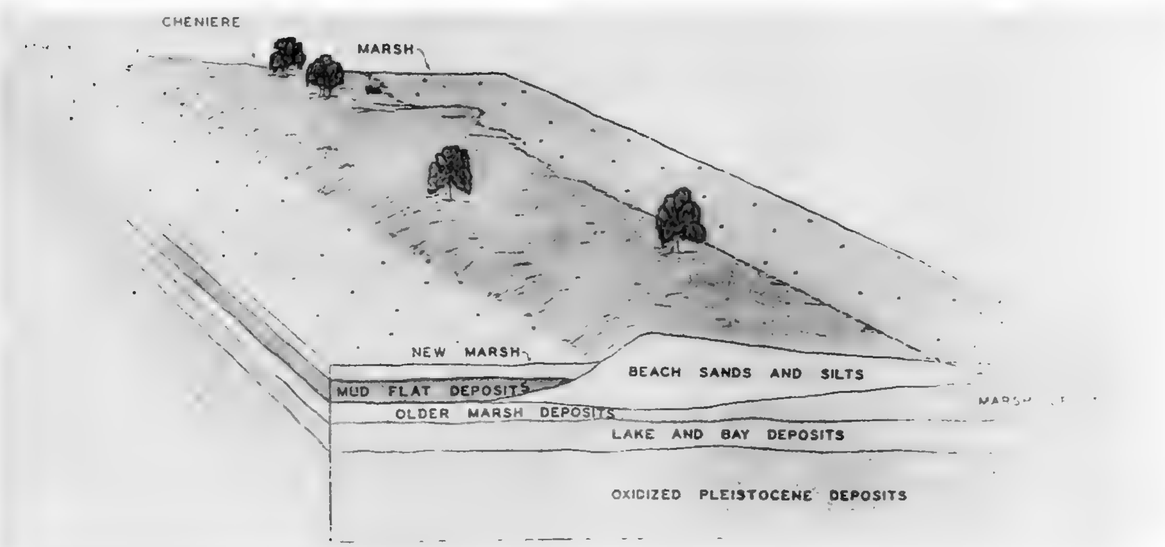

Figure 3. Cross section of a chenier.

NAVIGABILITY OF WATERWAYS

In order to travel in most of the area, one must rely on boats; therefore, an understanding of water-depth distribution is very important.

Water deep enough for an ocean-going vessel is present to within one to five miles of the Chandeleur Islands on the Gulf side. Chandeleur and Breton Sounds and Lakes Borgne and Pontchartrain are between five and twenty feet deep. The more shallow parts lie close to shore. Except for the large water bodies just mentioned, marshland lakes are nearly always less than six feet deep. Deeper water is confined to "passes" between lakes. Depths of lakes can generally be correlated with size—the larger, the deeper.

Tidal streams of this area vary in depth from less than a foot to a hundred feet in some cases, such as the channel between Lake Pontchartrain and Mississippi Sound. The width of a stream is a reflection of its depth; however, allowances must be made for its origin. Although origins are diverse, only two types need be considered: tidal streams originating between levees of former distributaries and tidal streams forming in "open" or unobstructed marsh.

Tidal streams develop between natural levees by adopting the remnant distributary course, producing rather straight, frequently long, channels. This pattern is evidenced even after five or ten feet of levee subsidence. However, streams that develop in marsh with no obstructions meander considerably and rarely have the straight pattern associated with tidal streams confined by levees.

The width and greatest depth of ninety tidal streams are plotted on Fig. 4. The chart is divided into three bands. The uppermost represents the depth-width relationships of tidal streams originating between levees; the central band represents the depth-width relationships of tidal streams forming in open marsh; the lower band shows that bends of tidal streams, like bends of gravity-motivated streams, are deeper than reaches. By measuring the width of a stream on an aerial photograph or map, it is possible to predict the approximate depth of that stream. Furthermore, the chart shows that streams originating in open marsh are deeper for a given width than those formed between natural levees. Although a few exceptions to the limits presented are known, the chart may be used with success at face value. However, consideration of the size and shape of a stream's drainage basins allows even closer depth prediction. The chart was constructed from data collected in easternmost Louisiana, but it has been found applicable throughout the marshlands of the State. This is an area of fine sediment and extremely low tidal range (1.5 feet). The effect of greater tides and coarser sediment on the depth-width relationship of tidal streams will be studied this summer in the New England coastal marshes. Necessarily, a new set of values will have to be compiled for this region.

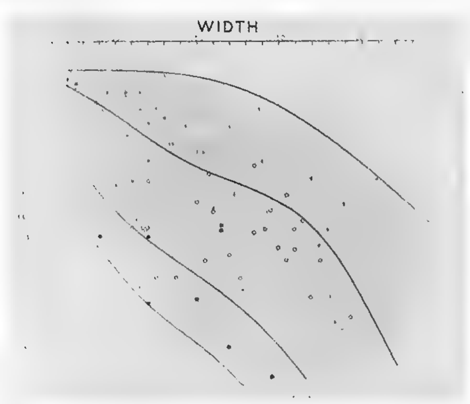

Figure 4. Depth-width relationship of tidal streams.

SEDIMENTATION

In addition to work on trafficability and navigability, a hundred and twenty sediment samples were taken and analyzed for grain size, sorting, organic content, percent shell, and glauconite and pyrite content.

It was found that "clean" sands are present near the Chandeleur Islands. Muddy sands or silts bottom the sounds, and the lake beds are composed of silty clay and clayey silt.

ECOLOGY

From the sediment samples about sixty species of Foraminifera and a similar number of species of Mollusca have been identified and their ecologic relationships determined.

HISTORY OF DELTAIC DEVELOPMENT

The sequence of deltaic development in this area is rather complicated, and only a condensed version can be presented.

The oldest features now present at the surface are the stranded beach ridges, or cheniers. Their age is on the order of 3000 to 5000 years (see Area 1, Fig. 5).

A very early subdelta was present, but very little is known about it. A second subdelta entered and spread over most of the area. Evidence of it has been found on the Chandeleur Islands, and an isolated remnant occurs within the area 2. Following the second subdelta, river flow began to shift into area 3. During this time much of area 2 was subject to marine erosion. As area 3 continued to enlarge, activity also was extended into area 4, and the delta was again extended an unknown distance seaward of the Chandeleur Islands. Deltaic sedimentation continued to about 1500 A.D. Since that time, the river has shifted to the south, and the older subdeltas have been subject to marine erosion.

Combined with physical evidence, refuse of Indian people, such as pottery, has aided in solving the developmental sequence just outlined and has been used throughout the State to help affix the chronological sequence of deltas.

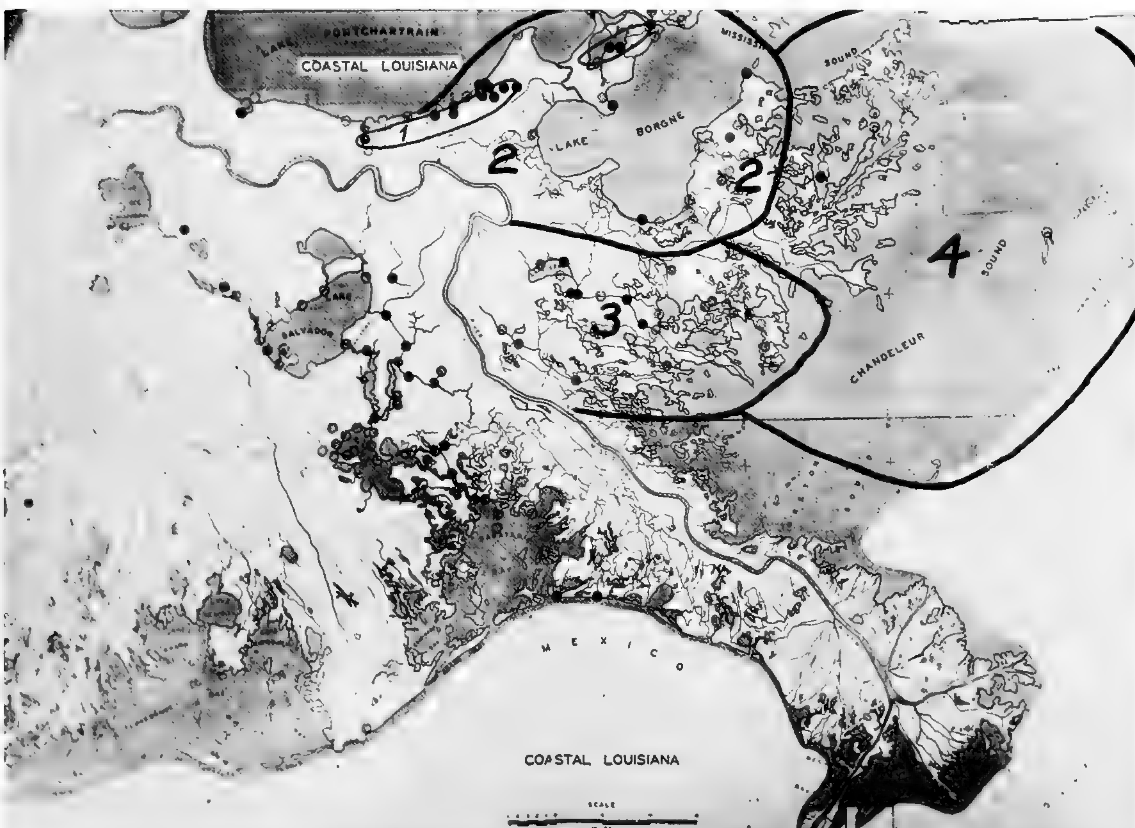

Figure 5.

CORRELATION OF CULTURAL REMAINS WITH THE PHYSICAL SETTING

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Contract N7onr-35608
Task NR 388-002

The deltaic area in south Louisiana is a very complex region from the standpoint of sequential development of the various trafficable units within the area. Threaded throughout the area is a network of natural levees; and in limited areas, salt domes, active and stranded beaches are present. These are the dominant characteristics in an area otherwise devoid of natural relief and are the only overland routes or passes available in the near-sea-level marsh. These trafficable units, in various degrees of decay, are directly related to the development of coastal Louisiana that has taken place over many thousands of years.

The master stream built its deltas for thousands of years before man entered the scene. It is estimated that the process of delta building has been going on for twenty to thirty thousands of years whereas man is believed to have lived in coastal Louisiana only during the last two thousand years. Since that time, however, many changes have taken place in the deltaic plain. As one of the district investigators on this project, I approached the problem of working out relative ages of trafficable streams by correlating the cultural remains of man with the physical remains of the river.

The area covered in the study extends from the Texas border in the west to the Mississippi border in the east. Approximately 15,000 square miles of near-sea-level lakes, marshes, swamps, bayous, and tidal channels were covered. The region is very rich in natural flora and fauna. Profuse vegetation and abundant sea and animal life offered many inducements to early man to settle in coastal Louisiana. He made his home on the most secure ground and took advantage of the many natural food resources abounding in the area. Mollusks were probably the most important of all marine life in the regions where they were abundant and numerous, and extensive shell heaps testify to their role in the economy of the early inhabitants.

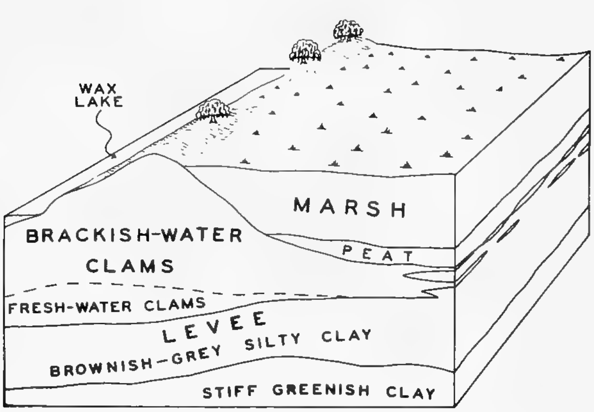

Figure 1. Shell midden.

The history of man in the deltaic plain follows the phases of the changing stream. As the river changed its course, it built in one area and buried its past in another. A new system of levees was built and since the old had lost their fresh water and continual sediment supply, they began to decay. Eventually, the requirements for human habitation were no longer available on these natural eminences and man was forced to move.

During a particular and limited time span, man usually performs his daily tasks in a certain manner. His various utensils are designed and made in ways that reflect his styles, those of his neighbors, and also those used by his predecessors. In coastal Louisiana, pottery fragments, or potsherds, are the only universal cultural remains that

have withstood both time and the elements. Although limited, these artifacts provide a relative scale when classified, whereby the sequence of time is measured by culture change. In order to ferret out the culture changes and consequently apply them to the changing river, archaeological methods have been used to order, collect, and classify the material.

Fortunately a competent group of archaeologists has worked out a chronological time scale for the Lower Mississippi Valley. This chronological scale was used as the basis for sorting and classifying the ceramic remains recovered during the project. At the present time, the following periods are recognized for the Lower Mississippi Valley:

Youngest . . .	Natchez Period
	Plaquemine Period
	Coles Creek Period
	Troyville Period
	Marksville Period
Oldest	Tchefuncte Period

The periods were usually named after the localities where the pottery complex was first recognized. For the purposes of this discussion these cultural divisions will be used to designate time periods.

It was in the shell middens that much of the cultural remains left by the aborigines was recovered. After the collections were made, the potsherds were classified according to type of design and means of manufacture and then segregated into a particular time period.

Figure 1, a cross section of an ancient submerged shell heap deposited by the Indians, is a good example of the sites visited. The shell heap is based on an old natural levee that has subsided beneath the marsh level to a depth of eight feet. The only feature that remains to indicate the presence of a natural levee is the top of the shell heap deposited there by early man.

This remnant feature is a frequent one throughout the deltaic area and is often the only clue to the location of former streams. Hence it was necessary to scrutinize the aerial photos of the area to locate trees and vegetation variations which almost inevitably indicate old Indian sites. After the site was located, bore holes were drilled to determine whether the site was resting on an old natural levee or an abandoned beach.

In addition to the identification of physical features, the Indian mounds and middens also suggest ecological environments of the surrounding water bodies. The cross section of the mound (Fig. 1) shows a layer of fresh-water clam shells (Unio) directly above the levee; capping this is a deposit of brackish-water clam shells (Rangia). This general stratification picture is found in many of the shell heaps in the area and indicates that a change in water conditions must have taken place. Salinity change is caused either by encroachment of Gulf waters due to subsidence or to the influx of fresh water due to active deposition of streams.

The sites investigated are indicated on Fig. 2 and show the widespread distribution throughout the area. Various ages of the pottery are indicated by different patterns on the map. Clusters of sites suggest areas or streams which were active during a phase of the cultural continuum and thereby indicate different shifts of the master stream. A very brief summary of the cultural periods from oldest to youngest is all that is possible in this limited discussion.

Tchefuncte is the oldest culture isolated in coastal Louisiana and pottery of this complex is found in both eastern and western Louisiana. The sites are usually associated with stranded beaches or Pleistocene terrace material. Subsidence and burial of Tchefuncte sites by more recent movements of the major streams has likely obliterated the record in the flood plain and it is doubtful that much information about this early period will be recovered from the central area.

Cultural remains of the Tchefuncte period give little definite information about the location of the master stream, but Marksville sites in the flood plain show more definite correlations. It has been established by competent geomorphologists that the Mississippi River occupied the Teche-Mississippi channel prior to its diversion to the eastern side of the alluvial

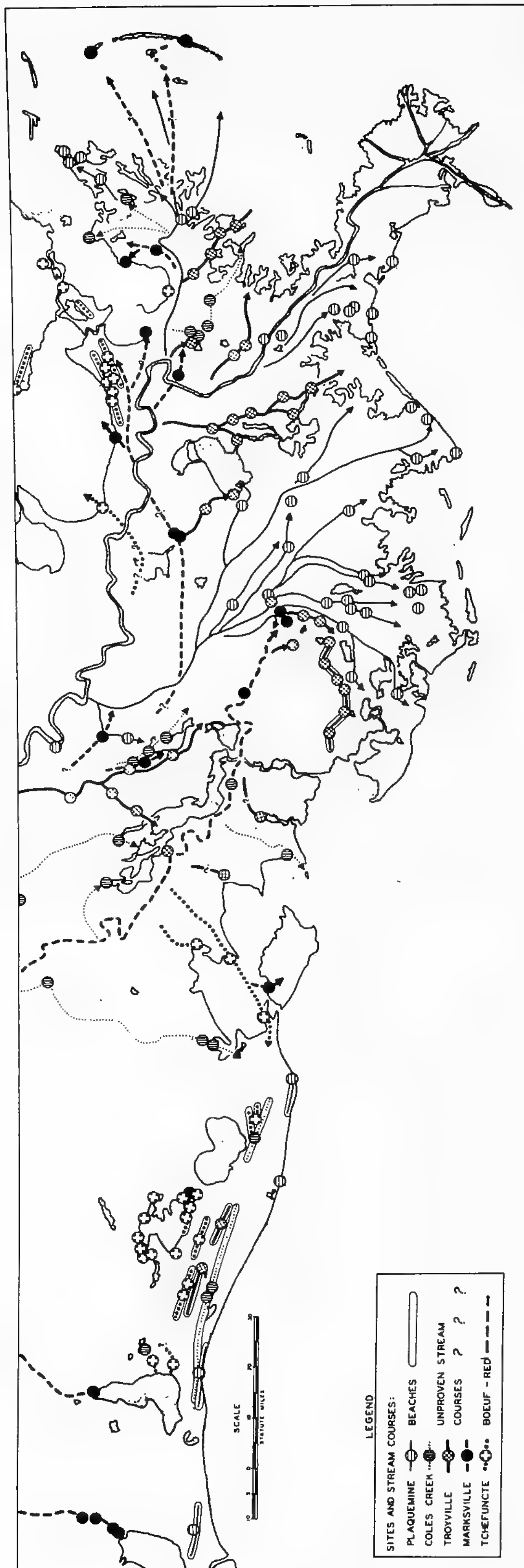

Figure 2. Over-all initial site occupation map.

valley. After the master stream abandoned the Teche-Mississippi course, the Boeuf-Red occupied the old entrenchment and therein built its levees. The presence of both the master stream and the Boeuf-Red in the Teche-Mississippi course is without question. The major problem is one of dating. The Gibson site (Fig. 3) located on the Teche-Mississippi course seems to furnish evidence as to the approximate time that the Boeuf-Red was occupying the channel. As is the case with many sites investigated during this survey, the Gibson site appears to be a mound complex of a late period. However, borings show that the mounds were built upon an older shell midden base, and pottery recovered from the midden is classified as Marksville. The midden material extends to approximately twenty feet below the ground level and is intermixed with red sediments. This indicates that the master stream was no longer flowing within the Teche-Mississippi entrenchment during Marksville times but rather that the Boeuf-Red was occupying the channel.

After the master stream left the Teche-Mississippi channel it diverted to the eastern side of the flood plain and extended its deltaic mass in the area presently known as the St. Bernard subdelta. Marksville sites as far out as the Chandeleur Islands indicate that the island arcs were land-connected during Marksville time and that they were probably part of an ancient subdelta extending at least to the island limits. The ceramics recovered during this study give the first hint that there may have been an earlier subdelta in this region than the one presently recognized.

The examples of cultural correlations with the natural setting given for Tchefuncte and Marksville periods are generally found throughout the remaining culture periods. During Troyville, Coles Creek, and Plaquemine periods the picture becomes clearer but the entire record is not always possible to interpret because of subsidence and aggradation. However recent streams leave the most distinct records and correlations are more easily determined.

The map indicates areas of site clusters and suggests the regions of deposition for each period. The relationship of the aboriginal population of coastal Louisiana and the physiographic features they inhabited is indicated from the numerous and widespread occupation sites throughout the region. Many sites in one area and the paucity of sites in others indicate the areas in coastal Louisiana where habitation was possible for any one period. These sites were located on the most stable ground in the unconsolidated deltaic mass and indicate the trafficable passes during a particular time period. Cultural remains have provided many clues regarding the natural setting during aboriginal time.

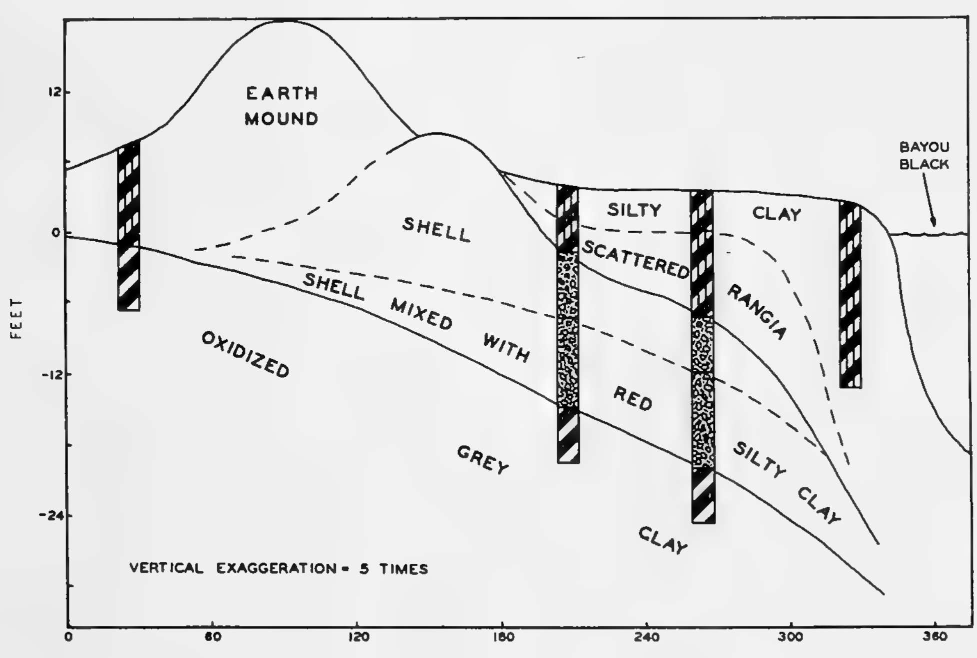

Figure 3. Cross section of Gibson site.

COASTAL MARSHES OF LOUISIANA

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Contract N7onr-35608
Task NR 388-002

Dr. Morgan, who was to present this paper as the concluding portion of the Louisiana section of this conference, was unable to be present, and I will attempt to fill in for him from some of his notes.

Dr. Morgan served as the Field Supervisor in the project, and Mr. Treadwell was one of five district investigators. We budgeted nine months for training time and fifteen months in the field for the district investigators. If our group had a full day at this conference instead of an hour or so to review the Louisiana project, we would have included the other investigators. They all have interesting stories.

Apart from the five district investigators, Mr. McIntire acted in the capacity of tying the whole thing together. He ranged throughout the various districts working on the problems of chronology and relative dating.

As we divided the Louisiana region, three of the investigators had areas of quite recent delta growth. Mr. Treadwell's talk concerned an area of recent growth in several deltaic successions, but all quite recent as far as the whole history is concerned. Two of the investigators covered roughly the western half of the Louisiana coast, and Dr. Morgan had intended to speak particularly about their region.

There is a little story that I am just going to sketch in a few minutes, which is somewhat dramatic as to what has happened on the western coast. In general, the eastern portion of Louisiana is the region of growth whose history does not go back too many centuries. The western coast, in a sense, is much older and smoother. Wave erosion in general has taken off the irregularities of the coast, so that there is quite continuous beach. In driving cattle westward, it is only necessary to swim them three times across this whole area. A great many cattle are grazed down here in the salt marshes, and actually the beach, as a cattle drive, has some consequence.

This region is one in which there has been a history of alternation between periods of the growth of marshes outward into the Gulf of Mexico, advancing the shoreline to the south, and periods when the beaches formed by the waves are driven northward across the marshes. Within recent centuries, most of this western half of Louisiana has been a region in which the beach has been driven back across the marshes.

Comparing the old Land Office Survey maps and whatever data we could get, some over 20 years old, we published to the effect that this coast on the whole was receding at the rate of about 600 feet per century. As a matter of fact, now that we have aerial photographs of this entire region taken in 1952, in addition to those of 1932, we know the average recession of this coast was 800 feet within this twenty-year period. The beach has been encroaching on the marsh much more rapidly. It also has grown in size. Anything coarse which can be picked up by the waves has been accumulated back on the beach.

The "coarse" material in this region is, for the most part, very fine sand or coarse silt, so that while the beaches are quite firm and appear white, still they are composed of materials among the smallest sand sizes. Other coarse materials are shells, bottles, pieces of steel

from old ships, and the like, all of which get incorporated in the beach deposit. One of the interesting things is the amount of Indian pottery which also gets incorporated because it is coarse. I think it is not possible to walk very far along the beach, the way McIntire walked around the beach, before a pottery fragment will be picked up. The beach has been straightened since Indians, who had used the pottery, had been living south of the current beach.

In general, this land has grown southward when the Mississippi River and Red River have discharged considerable amounts of sediment toward western Louisiana. At other times, as under recent conditions when the river has been much further east, the deposition of the delta has been concentrated away from this area. Those times are, in general, periods when the beach encroaches northward over the marshes. There have been alternations in the past, which are shown by the presence of old beach ridges, old cheniers, that lie back in the marshes. They each represent a time when sediments were deficient in quantity and the beach had a chance to be driven some distance inland.

There is ample mechanism for making a beach move inland and no mechanism for pulling a beach out. Once the accumulation, the sand, shells, etc., is driven back, there it stays. If sediments come in quantities, the marsh grows off the beach and the coast grows outward. Thus there is the alternation of the shoreline back and forth.

It is very interesting that the Indian story ties in nicely with this. As Mr. McIntire has shown, the oldest Indian settlements are predominantly inland, and the most recent ones are close to the coast.

The dramatic part of the recent history is this: starting a little over five years ago, the pattern changed. This coast, after that retreat of 800 feet in the twenty-year period prior to 1952, is starting to grow out again. This is another cycle that has set in.

There are several elements involved in the reason for this. In the first place, the Atchafalaya River, which comes down through a low basin, in the year 1900 was carrying 13 percent of the combined flow of the Lower Atchafalaya and the Mississippi. By 1950 this quantity had climbed to 31 percent. Every single decade since 1860, when artificial accumulations were cleared out on a stretch of this river, has seen more water coming down the Atchafalaya River than came in the decade preceding. The amount of alluviation in the Atchafalaya Basin has so overwhelmed the old water bodies that most of the lakes have been obliterated. Most of the lakes on the maps are very shallow. The basins are essentially full. People throughout the Atchafalaya Basin can recall old landmarks and points that in earlier times they used as guides in steering their boats, and now these landmarks are entirely inland. In one place, a prominent citizen of Louisiana had a hunting lodge out in the basin, and he built a levee around his place to protect it. Today the house is in a depression, with an alluvial plain surrounding it.

Since these lakes have filled up, they are no longer trapping the sediment. About six years ago the first of the sediment reached the Gulf of Mexico. With increasing discharges down the Atchafalaya River, not only is more sediment being brought down, but it is no longer being held in the basin; so the sediment is now coming to the Gulf.

In the Gulf, the present dominant set of the current is westward. Atchafalaya sediment has now formed an ooze or mud flat across this western coast, which has advanced westward about 125 miles during the last five years. We have probed this. You can drag a skiff over it and probe to determine the depth of this accumulation. You could run right through this ooze with any sort of a landing boat but it is up to six feet deep. We have mapped it in three dimensions for a report which we have submitted on this project. In many places the exposed flat is 100 yards in width at sea level. Pioneer salt water plants are now starting to get a good hold on it, and this soon will become a brackish salt marsh area. The old beach is now becoming a chenier.

These older cheniers were formed in the same way. In general, the chenier cross section, exhibited by Mr. Treadwell, indicates a deposit 8 to 10 feet deep of beach material, overlying marsh and various other things, and up to a mile or so in width. Of course, any such diagram is greatly exaggerated in its vertical and horizontal scales, but these are the general dimensions.

As far as land trafficability is concerned, the chenier units are excellent, and the stretch along Grand Chenier, which was a beach not too many centuries ago, is actually trafficable by trucks for over ninety miles.

The cheniers are also sources of potable ground water and are populated. There is quite a little settlement in remote Pecan Island. Chenier au Tigre has been ruined recently because of the mudflat that now isolates the beach. This old resort area has disappeared because of mudflat development starting five years ago. On cheniers people dig only a few feet to find a source of water. Troops could be brought in and landed in such places. and could stay there for some time on perfectly firm surroundings.

The chenier belt shows a pattern narrowing to the west. It affords excellent trafficability in directions parallel to the coast. Transversely, however, the marshes between the cheniers are generally too soft, and waterways must be used to get from one ridge to another.

One of the tedious things to map is the inner extent of the marshes. This boundary has been shown on the maps exhibited. North of the boundary is all good substantial dry land. Thus, any route followed in crossing the marshes of Louisiana would end in the inner part on the good firm dry land.

Well, those are the things that Dr. Morgan would have said. He would have said a good deal more, too, but from his notes, and from the time I have available, I have tried to boil down some of the points. I might say that these are all generalizations. We have completed the detailed mapping of seventy-four quadrangles. Our field parties have done the soundings for depths indicated on the maps. They show controlling water depths, and show them quite accurately, and also define areas of firm land.

SUMMARY OF DISCUSSION ON PAPERS BY THE GROUP FROM LOUISIANA STATE UNIVERSITY

A question was raised as to the effect the increasing flow down the Atchafalaya was having on the lower Mississippi. In answering, Dr. Russell made it clear that he expressed only his own views because he felt the problem had some political aspects. He pointed out that the city of New Orleans needs a water supply and that this need could be easily fulfilled. There is an abundance of water a few miles to the north that could be piped into the city instead of using Mississippi River water. As far as the port is concerned, Dr. Russell felt the diversion of the Mississippi into the Atchafalaya would be an excellent thing. If a dam should be built in connection with the diversion, he would prefer a dam across the Mississippi because a dam across the Atchafalaya or Old River, would concentrate the flood flow down the channel and New Orleans would begin to suffer from floods. This would be extremely dangerous. The hydraulic gradient at extreme flood down the Mississippi is almost the same as at the lowest stage down the Atchafalaya. The Atchafalaya has the ability to accomplish the drop to sea level in half the distance needed by the Mississippi.

In addition, Dr. Russell suggested that a dam across the Mississippi would reduce the number of days of fog in the passes. Fog, the chief fear of pilots, is caused by the cold river water coming into the warm Gulf water.

However, the river towns' water supply is the really critical thing, and that could become a catastrophy unless steps are taken to bring decent water into the region.

In discussing the problems of deposition at the mouths of the Mississippi it was noted that the two commercial outlets of the river are artificially maintained. The other outlets barely maintain a depth of four feet over their bars. During time of flood, even with only a foot of water, it is possible for a small boat to cross the bars because there is only a soft ooze to plow through. However, at time of prolonged low water, the bottoms have hardened and a boat drawing four feet has a difficult time coming in a pass not maintained by the U. S. Army Engineers. Each pass tends to build a barrier, and therefore the natural depth of any pass is less than one fathom.

THE MANGROVE SWAMP OF THE PACIFIC LITTORAL OF COLOMBIA

Robert C. West
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Contract Nonr-454(00)
Task NR 388-059

A study has been made of the physical characteristics of the Pacific coast of Colombia and of certain relationships between these characteristics and problems of travel and living along the coast. Data for these observations were obtained through field work done under an ONR contract, which calls for a reconnaissance survey of the geography of the Pacific lowlands of Colombia.

The Pacific littoral of Colombia is characterized by two distinct coastal types: (1) A low, alluvial coast, fringed by a dense mangrove swamp forest, stretches from the Ecuadorean border northward for more than 400 miles to Cabo Corrientes. (2) From Cabo Corrientes to Panama and beyond, the coast is mountainous; cliffed headlands alternate with short sand beaches formed in small coves.

Only the low, swampy mangrove coast is considered here, for it presents special problems for travel and subsistence; such problems may be characteristic of most mangrove coasts of the humid tropics. Moreover, low alluvial coasts are the least understood of all coastal types in terms of physical processes and development.

The mangrove swamp of the Pacific littoral of Colombia occupies the tidal fringe of a narrow alluvial coastal plain. This plain, 5 to 30 miles wide, is being formed by material deposited by streams flowing from the western versant of the Andes. These streams carry an enormous volume of water, and probably a large load, for they drain areas having an annual rainfall of 200 to 400 inches. A large tidal range—an average of 10 to 12 feet—occurs along this coast.

Two types of mangrove swamp coast exist along the Colombian littoral: (1) One is characterized by dense mangrove forest growing to the edge of the sea and fronted by extensive mud flats at low tide. Such a coast occurs in areas protected from strong wave action, as in bays or behind shoals. (2) The other type of mangrove coast is characterized by the development of extensive sand beaches along the seaward edge of the forest. Such beaches occur in sections of strong wave action and longshore currents. Sand for building of beaches comes mainly from stream load, which is effectively sorted by wave action. Minor amounts of sand probably derive from erosion of occasional small headlands that occur south of Cabo Corrientes, such as that near Buenaventura. Approximately 45 percent of the mangrove coast of Colombia is fringed by sandy beaches.

VEGETATION ZONES ALONG THE COAST

Along most of the mangrove coast there exists a definite zonation of vegetation associations inland from the shore. Each of these zones is related to given physiographic conditions, and each presents peculiar problems for living and travel. These zones are as follows: (1) The beach zone, with its low shrubs, creeping vines, and stands of coarse grass. (2) The mangrove zone, which consists of dense tidal forest of various species of mangrove. These line the lagoons immediately back of the beach, and continue inland for a distance of one-half to two miles. This zone penetrates much farther inland along the lower parts of streams, where

salt or brackish water occurs at high tide. (3) The fresh-water swamp, which is flooded by fresh to slightly brackish water from rivers during high tide. One-half to two miles wide, the vegetation of this zone is comprised of the giant nato tree (Mora megistoperma) and clumps of the naidí palm (Euterpe, sp.), highly reminiscent of the nipa palm association of Southeast Asia. (4) On slightly higher ground immediately inland from the alluvial areas affected by tide, begins the fourth zone—the vast equatorial rainforest that covers the rest of the coastal and western slopes of the Andes to an elevation of four to five thousand feet.

This peculiar zonation of vegetation appears to be typical of most mangrove coasts of the world. It is described for the Malaya Peninsula by Watson[1] and by Dobby,[2] for the west coast of Africa by Grewe,[3] and for the Guiana coasts of northern South America by Martyn.[4] Further field work is necessary to ascertain the actual distribution of this zonation along other mangrove coasts.

With the gradual extension of the coast seaward through deposition, there seems to be a slow successional change within the vegetation zones. As the floor of the fresh-water swamp becomes higher and better drained, equatorial rainforest plants invade; eventually fresh-water swamp plants encroach upon the landward margin of the mangrove. In turn, mangrove succeeds the beach associations as the beaches become remnants cut off from the ocean front by formation of new strands and buried by tidal muds. Finally, the beach plants colonize newly deposited stretches of sand along the ocean front.

THE BEACH ZONE

The beaches are made up of fine, compact sand, sorted from the river load by wave action and distributed up and down the coast by longshore currents. Many beaches are five to six miles long. Their width varies from 100 to 400 yards at low tide to zero to 25 yards at high tide. They are smooth and firm and could support heavy motor vehicles. Some beaches, however, are crossed by rivulets, whose beds are often composed of quicksand. Fresh to slightly brackish water can usually be found on the beaches by digging a few feet below the surface. Moreover, tidal ponds, called pozos, form in slight depressions and shallow lagoons on the landward side of beaches. At low tide these ponds afford an abundant supply of fish which natives catch by spearing or by poisoning. Small fishing villages often occur at the end of beaches near the mouths of estuaries or rivers. Groves of coconuts, small patches of maize and manioc are often cultivated in the sandy soil of beach ridges near the villages. In terms of travel and living, the beach zone appears to be the most favorable of those along the mangrove coast.

Beach formation has been one of the major factors in the seaward extension of the low coastal plain. Remnants of beach ridges separated by mangrove-enclosed lagoons occur in abundance back of the present beaches. Due probably to slight sinking and alluviation, the beach ridge zone is invaded by mangrove and eventually becomes part of the swamp.

THE MANGROVE SWAMP

This zone presents the most difficult problems in terms of travel and subsistence. The most conspicuous tree of the swamp is the giant red mangrove (Rhizophora brevistyla) which

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[1] Watson, J. D., "Mangrove Forests of the Malay Peninsula," Malayan Forest Records, No. 6, pp. 1-275, 1928.

[2] Dobby, E. H. G.; "Southeast Asia," p. 67, London, 1950.

[3] Grewe, F., "Africanische Mangrovelandschaften. Verbreitung und wirtschaftsgeographische Bedeutung," Wiss. Veröff. d. Deut. Mus. f. Länderkunde zu Leipzig, N. F. 9, pp. 103-177, 1941.

[4] Martyn, E. B., "A Note on the Foreshore Vegetation in the Neighborhood of Georgetown, British Guiana," Journal of Ecology, Vol. 22, p. 293, 1934.

grows in solid stands; individual plants often reach heights of 80 to 100 feet. At low tide the gnarled prop roots of this tree, four to ten feet high, are completely exposed, rising from a surface of soft, brackish ooze, into which a heavy man would sink to his knees. At high tide, however, the Rhizophora swamp can be penetrated along a maze of tidal estuaries and creeks in small boats or canoes.

Although the Rhizophora is the dominant mangrove component, it is best developed along the edge of tidal channels where there is complete flooding by the tide twice each 24-hour period. Inland, there exist round patches of low growth, four to six feet high, composed of dwarfed Rhizophora with stunted prop roots, mixed with black mangrove (Avicennia nitida) and other brackish water swamp plants. These patches of low growth occupy ground that is higher and drier than the channel banks. They are flooded usually by semimonthly spring tides only. The soil is peat-like, soggy, and quaking underfoot; a heavy man sinks to his ankles in the top muck. Often in the center of these patches are found hammocks of the naidí palm, a plant characteristic of the fresh-water swamp, or in some instances even clumps of equatorial rainforest. The centers of these patches are the highest, driest, and firmest parts of the mangrove swamp, but they are extremely difficult to reach.

The curious occurrence of such patches of low growth on higher, drier ground is typical of other mangrove areas. For example, along the coast of Malaya such areas are called "byiaks" and are readily noticed on aerial photographs.[5] The formation of such features is probably due to the slow rise of land through the decay of mangrove vegetation. The underlying peat contains remains of large Rhizophora roots and trunks.

Another curious feature characterizes the mangrove swamps of the Pacific coast of Colombia. Within the swamp back from the seacoast for a distance of one-half to one mile, one frequently encounters along tidal channels small areas of sandy material which rise slightly above the general level of the swamp muck. These sandy "islands" are locally called "firmes." They are sites of human habitation within the mangrove swamp, fresh water is usually found at a depth of three to four feet below the surface, and coconut palms, patches of maize and other crops are grown. These peculiar sandy "islands" appear to be remnants of old beach ridges that have been largely destroyed with the general seaward advance of the coast.

THE FRESH-WATER SWAMP

The fresh-water swamp affords greater ease of travel and better possibilities for food supply than the mangrove. The prop roots of red mangrove and the soft brackish muck are absent. Yet the daily flooding by river overflow makes most of the swamp penetrable only by canoe, during high tide. During the past 25 years natives from up-river have been utilizing the flooded banks of the rivers within this zone for growing rice. This development has lessened the problem of obtaining food within the coastal area.

Although malaria occurs throughout the Pacific coast, the Anopheles mosquito prevails in the fresh-water swamp zone. Pools of standing fresh water, left by the retreating tide, form excellent breeding places for these insects. At dusk and at dawn swarms of mosquitos and other biting insects (mainly black flies and gnats) occur around every hut and canoe to pester unprotected occupants to distraction. Smaller numbers of mosquitoes breed in the mangrove zone (chiefly in small bodies of rainwater that collect in epiphytic plants on the trunks of large trees) and in the beach area (principally in the shallow wells dug into the sand). Curiously, few mosquitos are encountered along the middle and upper courses of the streams that flow across the narrow coastal plain.

MANGROVE AS A GEOLOGIC AGENT

It is commonly stated that red mangrove (Rhizophora) is an important agent in the seaward advance of coastlines. It is supposed that Rhizophora is the pioneer colonizer of

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[5]Stamp, L. D., "The Aerial Survey of the Irrawaddy Delta Forests," Journal of Ecology, Vol. 13, pp. 262-276, 1925.

partially submerged mud banks and shoals, that the growth of young plants fixes the shoal, and that the later development of prop roots of the plant is instrumental in building the shoal into an island, which eventually is attached to the mainland by alluviation. It is true that the prop roots of mature mangrove probably serve to catch fine particles in water and thus aid in deposition. However, along the Colombian coast and elsewhere,[6] it is observed that land must be entirely emerged before it is colonized by plants, that the first colonizers are not Rhizophora, but black mangrove (Avicennia), and that Rhizophora will not establish or even maintain itself except in quiet saline to brackish water in protected bays or along coastlines protected from wave action by offshore bars or shoals. Strong wave action appears to preclude the development of mangrove and destroys existing stands. Constant shifting or destruction of mud shoals and of offshore mud or sand bars causes continual change of locale of strong wave action along mangrove-bordered bays. At such points wave action immediately begins to erode the muck and underlying peat-like material which supports the mangrove, eventually killing extensive areas of Rhizophora and Avicennia forest.

The Pacific coast of Colombia contains but a small fraction of the world's mangrove swamp; nevertheless, it affords an excellent exampie of the physical and related travel and subsistence conditions to be expected within such a type of littoral. Detailed comparisons with other mangrove areas of the tropics would doubtless reveal interesting and valuable facts. Unfortunately, however, although numerous botanical and ecological studies of mangrove swamps have been made for small areas, the world distribution of that feature has never been adequately mapped, and the world cultural and physical geography of mangrove swamps remains to be studied.

SUMMARY OF DISCUSSION

Some comments were made on the ability of mangroves to pioneer in areas protected from strong wave action. The black mangrove (Avicennia) appears to be much more tolerant of high temperatures than the red mangrove (Rhizophora) and may be more tolerant of salt. Consequently it is found nearer the sea. In some areas, as along the Gulf Coast of Florida where there is little sediment in the water, the prop roots of the mangrove are not too effective in building shoals.

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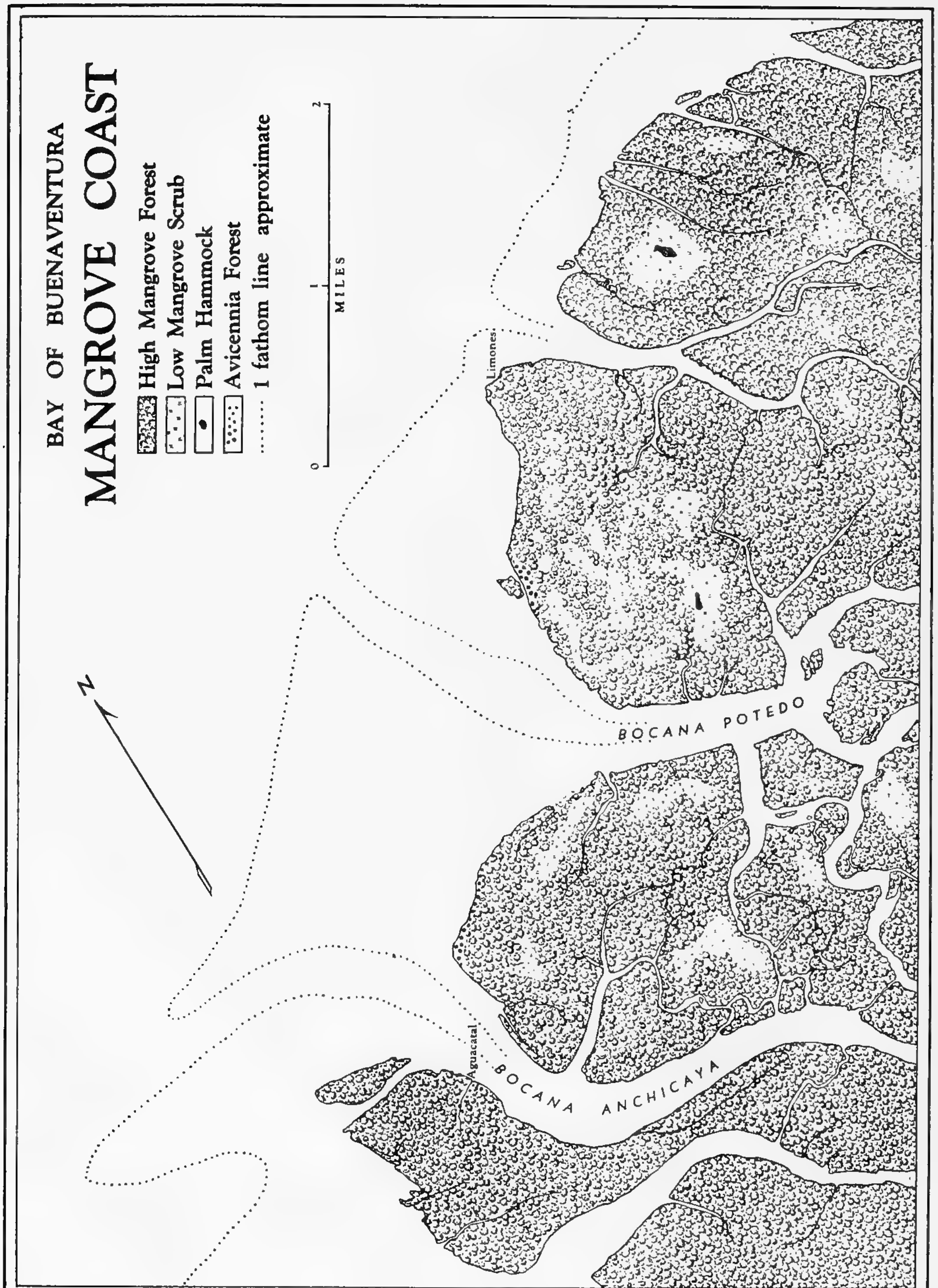
[6] See, for example, Freyberg, G. von, "Zerstörung und Sedimentation an der Mangroveküste Brasiliens," Leopoldina, Vol. 6, pp. 69-117, 1930.


BAY OF BUENAVENTURA
MANGROVE COAST
High Mangrove Forest
Low Mangrove Scrub
Palm Hammock
Avicennia Forest
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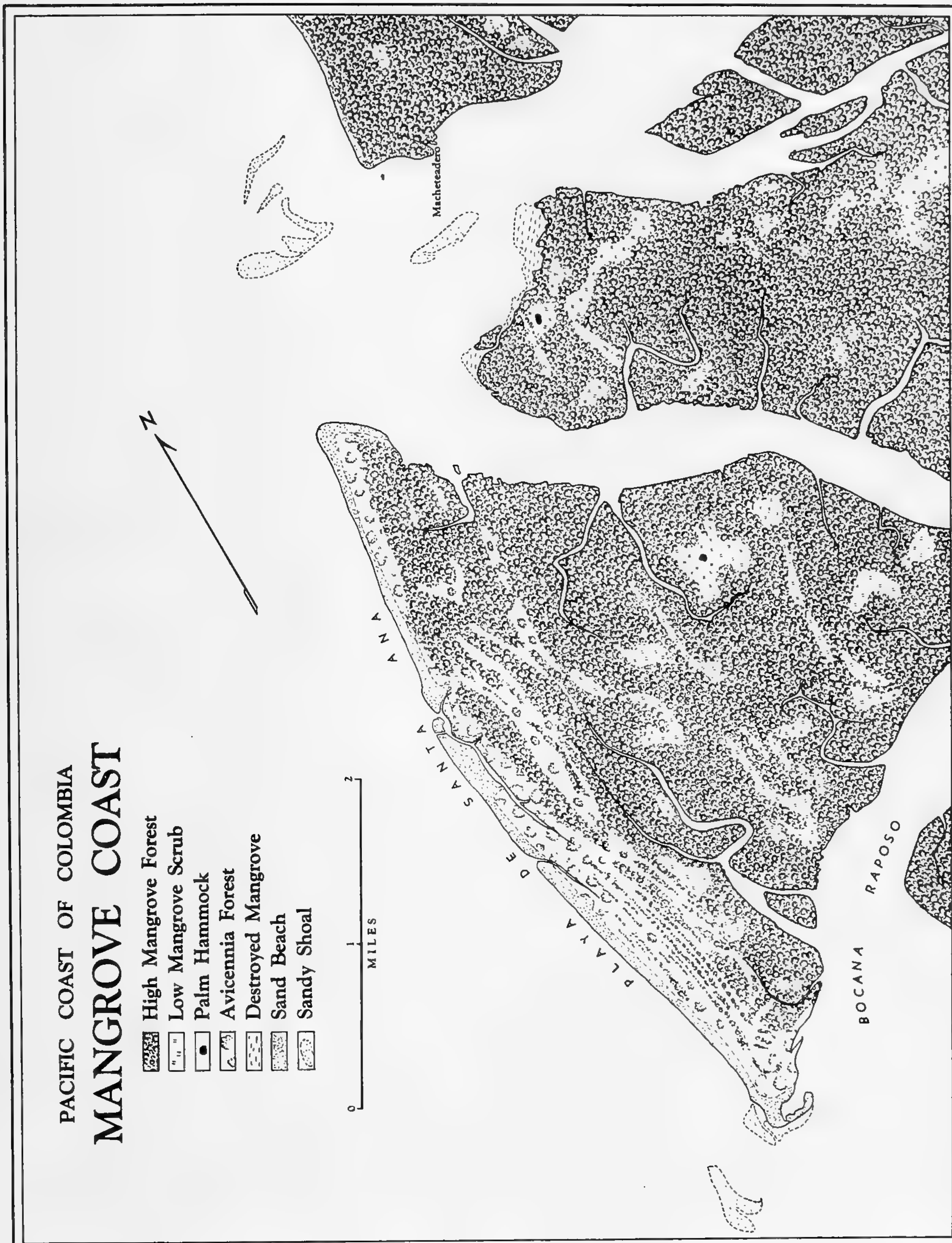
PACIFIC COAST OF COLOMBIA
MANGROVE COAST
High Mangrove Forest
Low Mangrove Scrub
Palm Hammock
Avicennia Forest
Destroyed Mangrove
Sand Beach
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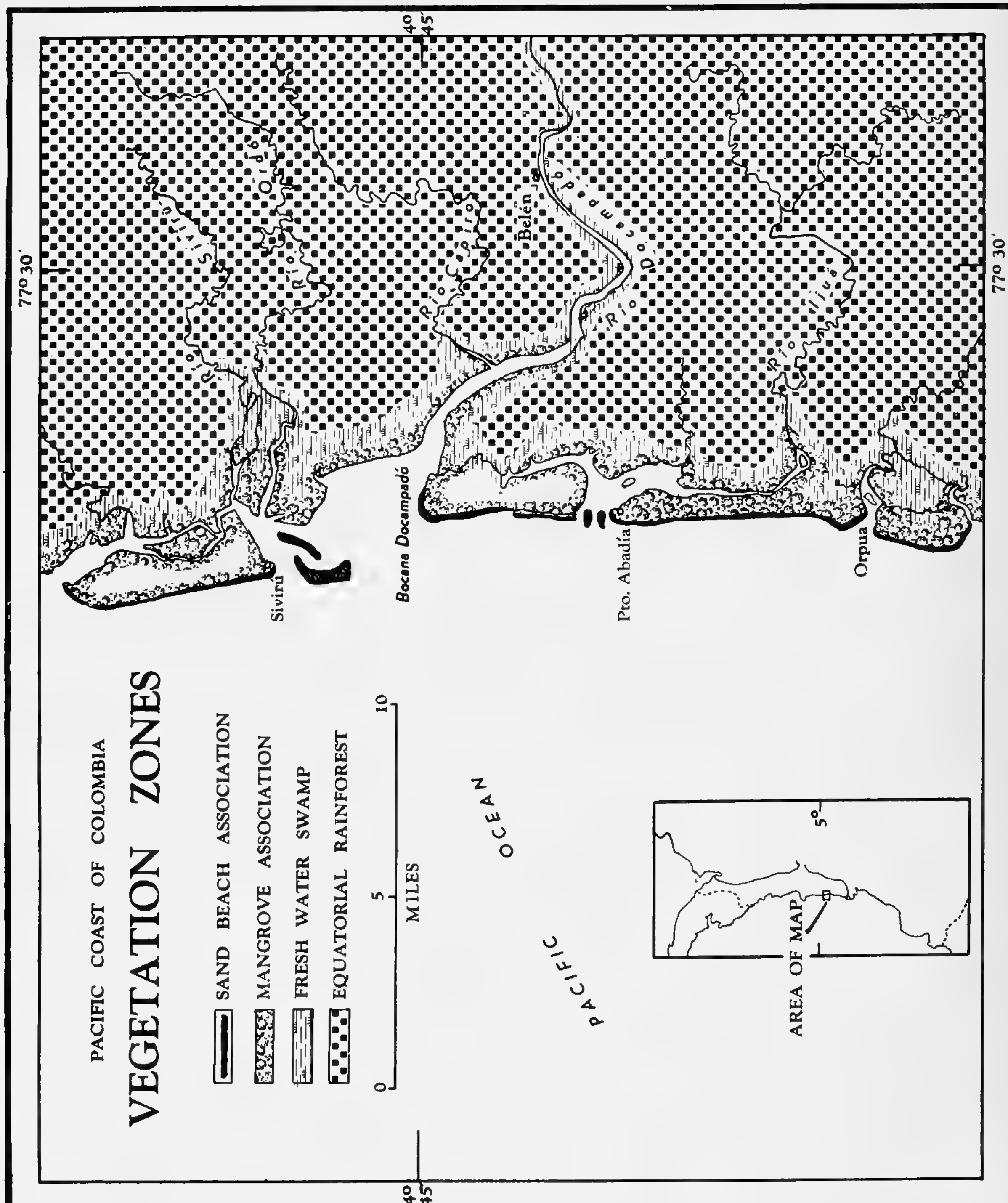
PACIFIC COAST OF COLOMBIA
VEGETATION ZONES
SAND BEACH ASSOCIATION
MANGROVE ASSOCIATION
FRESH WATER SWAMP
EQUATORIAL RAINFOREST
0
5
10
MILES
PACIFIC
OCEAN
AREA OF MAP
5°
Siviru
Bocana Docampadó
Pto. Abadía
Orpua
Belén
Río Siviru
Río Ordó
Río Capiro
Río Docampadó
77° 30′
4° 45′

COASTAL DUNES

H. T. U. Smith
University of Kansas

Contract Nonr-583(06)
Task NR 387-012

INTRODUCTION

Most of the papers presented at this symposium are concerned with projects which are well along toward completion. I am perhaps at somewhat of a disadvantage in discussing a project which is only beginning, and therefore have little in the way of results or conclusions to offer. I will endeavor, however, to outline some of the main points of interest in my project and provide some degree of orientation in (a) the study of coastal sand dunes, (b) the practical implications of such studies with particular reference to terrain intelligence through air photo interpretation, and (c) engineering problems encountered in dune terrain.

OCCURRENCE OF COASTAL DUNES

Sand dunes of various sizes and shapes are widespread along the low-lying coasts of the world, and in many regions occupy up to 10 percent of the total length of the shoreline. In some places, of course, they occupy much more of the shoreline. They are found along the coasts of both arid and humid regions, in all latitudes, bordering a wide range of types of inland terrain, and occur both on the mainland and on barrier islands. In all areas where coastal dunes occur, effective planning of engineering and military operations requires that due consideration be given to the special characteristics of dune terrain.

In addition to coastal areas proper, the shores of inland seas and lakes, ancient abandoned shorelines now well above water level, and the beds of dry lakes in arid regions all provide sites for dune topography.

The scale of the dune topography ranges widely from place to place. In height, the dunes range from less than 10 feet to more than 200 feet. In some places, as along the southern and eastern shores of Lake Michigan, dunes constitute the highest hills, if not the only hills, of the coastal region. In considering width, it is the width of the dune belt rather than the individual dunes which is significant, and this also ranges widely, from less than 100 feet to many miles. Height and width do not necessarily vary together.

The terrain on the inland side of the coastal dune belt may be of many varieties. In some places it is essentially flat, in other places it is hilly. In many localities, swampy ground or actual ponds and lakes are found on the inland border, and in fewer areas there are continuous bodies of water.

In the United States, examples of coastal dunes are numerous. Along the Atlantic coast, narrow zones of low dunes are common from Florida to North Carolina, and limited areas of higher dunes are found near Kittyhawk, North Carolina; Cape Henry, Virginia; Cape Henlopen, Delaware; and Cape Cod, Massachusetts. Along the Gulf Coast, dunes occur at many places in Florida and Texas, the largest area being in southern Texas. On the Pacific Coast, important dune areas are located near Los Angeles, San Luis Obispo, Monterey, San Francisco, and Eureka, in California; along roughly one third of the Oregon coast; and at many points along the coast of Washington. In the Great Lakes area, dunes of unusual size border the southern and eastern shores of Lake Michigan. In Europe, coastal dunes are widespread along the coasts of north Germany, Denmark, Belgium, northern France, and the Bay of Biscay, and more sparsely

distributed around the British Isles and the Mediterranean. In north Africa, there are numerous areas of coastal dunes, and in some places the great areas of interior dunes come so close to the coast as to enter into consideration of coastal problems. In South America, dunes are exceptionally well developed at many places in the desert coastal strip of Peru.

GENERAL DESCRIPTION OF COASTAL DUNES

The appearance of dune areas ranges from that of comparatively simple and well-defined unit dune forms to complex mazes of ridges, mounds, and hollows with seemingly extreme degrees of disorder. The simpler forms comprise the following:

(1) Foredune ridges, or elongate mounds of sand up to a few tens of feet in height, adjacent and parallel to beaches.

(2) U-shaped dunes, arcuate to hairpin-shaped sand ridges with the open end toward the beach.

(3) Barchans, or crescentic dunes, with a steep lee slope on the concave side, which faces away from the beach.

(4) Transverse dune ridges, trending parallel or oblique to the shore, and elongated in a direction essentially perpendicular to the dominant winds. These dunes are asymmetric in cross profile, with a gentle slope to the windward and a steep slope on the leeward side.

(5) Longitudinal dunes, elongated parallel to wind direction, and extending perpendicular or oblique to the shoreline; cross profile is typically symmetric.

(6) Blowouts, comprising a wide variety of pits, troughs, channels, and chute-shaped forms cutting into or across other types of dunes or sand hills. The larger ones are marked by conspicuous heaps of sand on the landward side, assuming the form of a fan, mound, or ridge, commonly with a slope as steep as 32 degrees facing away from the shore.

(7) Attached dunes, comprising accumulations of sand trapped by various types of topographic obstacles.

The above types of dunes may exist in either an active or a stabilized condition. The active dunes have loose, bare sand on all or part of the surface, and undergo continuous change in size, shape, and/or position under the impact of strong winds capable of drifting the sand. Stabilized dunes are those so well covered by vegetation as to inhibit further drifting of the sand. Different degrees or stages of stabilization may be distinguished, and in advanced stages a well-developed soil is present. Any dune may become stabilized if conditions permit the spreading of vegetation over its surface. Also, any stable dune may become active again if the cover of vegetation is weakened or destroyed, either locally or generally, as by fire, deforestation, excavations, climatic changes, etc. Large-scale reactivation of dunes by the work of man has been known to do great damage by overwhelming arable lands and settlements and removing the dune areas themselves from profitable uses.

The simpler types of dunes, whether active or stabilized, exhibit a wide range of modifications and variations, and the over-all characteristics of dune assemblages are subject to innumerable complications by the crowding or merging of individual dune forms, by alternations between activity and stabilization, by the juxtaposition or superposition of one type or scale of dune form on others of different type or scale, by shifts in wind direction during dune building, by wave erosion, and by other factors. Much remains to be learned both about the general principles governing these complications and about the detailed features of specific areas of coastal dunes.

RECOGNITION AND INTERPRETATION OF DUNE TERRAIN

Identification of dune terrain is generally possible from analysis of landforms as shown on air photos. For the simpler types of dunes, this may be done in an empirical way by personnel of limited scientific training. For the more complex types, however, and for dune areas which have undergone modification during long intervals of stabilization, the experience and training of the specialist are required.

Interpretation follows after identification and may be concerned with one or more of the following factors:

(1) Direction of the effective sand-moving winds. For areas in which no meteorological records are available, dune forms may provide the best available data on wind direction. Some caution is necessary in making interpretations, however, for such a factor as unequal exposure to winds from different directions may introduce qualifications, particularly in the case of partially stabilized dunes.

(2) Offshore conditions. Analysis of the source of sand supply for dune building may lead to significant conclusions as to nature of the bottom on the seaward side. In some places it has been determined that the sand now incorporated in stabilized dunes could have been derived only from sandy flats some distance from the present shoreline and exposed at a time when sea level was much lower.

(3) Present trend in coastal development. Tendencies toward erosion or fill along the shore, important in the planning of permanent installations, may be recorded in the form and pattern of dunes.

(4) Ground and underground conditions. The range in size of sand grains that are readily moved by the wind is comparatively small, thus dune sand is characteristically well sorted and generally is composed mainly of grains between 1/2 and 1/8 mm in diameter. Identification of dune topography, therefore, leads at once to the conclusion that incoherent, fine sand lies at or near the surface. Some implications of this fact are outlined in a following section. Although the characteristics of the subsoil, as noted above, are relatively constant, the nature of the soil on stabilized dunes ranges widely, particularly with respect to thickness and degree of stability. Correlation of these characteristics with the details of dune morphology is a matter for continued research, and it is hoped that this project will contribute useful data.

(5) Other terrain conditions affecting military operations, as discussed in the next section of this paper.

The general directions in which interpretation, particularly photo interpretation, of dune terrain for practical purposes may proceed are thus marked out. Progress in these various directions, however, will be conditioned to a large extent by continued basic research on the geology and geomorphology of the widest possible variety of coastal dune areas and types.

ENGINEERING AND MILITARY ASPECTS OF DUNE TERRAIN

Dune sand in general has the following characteristics which are important from the engineering standpoint:

(1) It is easily excavated, but sides of excavations require support.

(2) Drainage is excellent, except in low-lying hollows or depressions.

(3) It provides good foundations for roads and other structures, if properly confined.

(4) It provides excellent fill material, and has been used extensively for this purpose near Chicago.

(5) Unless blended with coarser sand, it is unsuitable for concrete aggregate, but is suitable for bituminous surfacing.

(6) Special protective measures against sand drifting are necessary where the surface is bare.

(7) Stabilized surfaces readily revert to drifting if improperly handled.

Dune topography also has the following surface characteristics which are significant for military operations:

(1) Dune ridges and blowout hollows offer good cover from ground fire, and the nature of the sand tends to muffle and restrict the effects of bombs and shell fire.

(2) Dunes commonly provide excellent concealment from the ground view.

(3) In many coastal areas high dunes provide the best available observation points.

(4) Special camouflage methods, such as simulated blowouts, might be adapted to dune areas.

(5) Tracks of men and vehicles on bare sand are quickly obliterated if the wind is blowing strongly, and the same effect probably could be obtained by airplane propellers or helicopter rotors.

(6) Actively blowing sand introduces special maintenance problems for equipment.

(7) The readiness with which stabilized dune sand reverts to the actively blowing condition introduces an additional factor in planning operations or installations, and offers a possible means of harassing enemy-held coastal territory.

(8) Bare dune sand provides poor footing for men and for wheeled vehicles with ordinary equipment, but offers fair to good trafficability for tracked vehicles or for wheeled vehicles with 4-wheel drive and oversize, low-pressure tires, within certain limitations of slope.

(9) Stabilized sand surfaces under certain conditions offer good trafficability initially but tend to deteriorate rapidly if traffic continues.

(10) In swampy areas, dune ridges may provide the best available trafficability.

(11) Various types of dune topography provide innumerable combinations and patterns of channels and obstacles for movement. Where the dunes are strongly asymmetric, movement may be a one-way proposition. Movement toward inland points is facilitated by some types of dunes and greatly retarded by others. Knowledge of the general types of dunes present permits rapid appraisal of the possibilities for movement.

CONCLUSIONS

Dune topography constitutes one important type of coastal terrain, and has certain special characteristics that play an important part in the planning and execution of operations in the areas concerned. Some of these characteristics are essentially the same for nearly all types of dunes, whereas others are more individualized and more specifically governed by local conditions. Proper appraisal of the latter must be based on continued research on the geography and geology of a wide range of representative areas, in as many different types of environment as possible. Such studies may be expected to make for more rapid and efficient procurement of terrain intelligence for those coastal areas where dunes occur, by air-photo interpretation or by other procedures. It is hoped that the project here represented will contribute to that general objective.

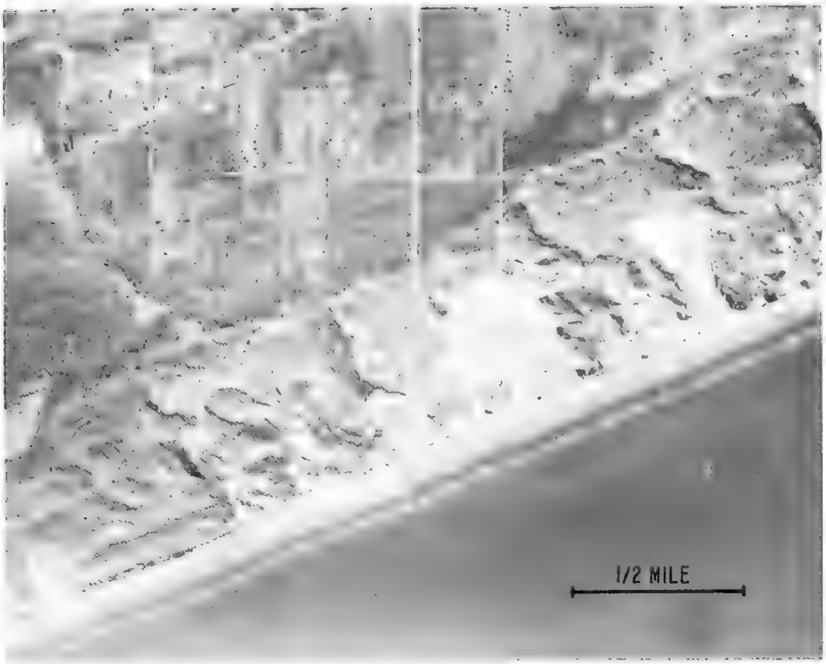

Figure 1 - Complex dune topography along the southern shore of Lake Michigan. The light-colored areas are active blowouts, and the contorted ridges are stabilized dunes. Maximum height of the dunes is slightly less than 200 ft. The complexity of this dune area is due to the superposition of different types of dunes of different ages. (U. S. Department of Agriculture photo)

Figure 2 - Broad belt of active dunes along the southern Oregon coast. (U. S. Department of Agriculture photo)

SUMMARY OF DISCUSSION

Much of the discussion concerned sand dunes as indicators of wind direction.

It was pointed out that if there were very strong, persistent offshore winds, there would be few dunes. Dunes are built only where the onshore winds are more vigorous than offshore winds, unless there is enough vegetation to prevent the offshore winds from contacting the sand. Wherever blowouts rise high enough to top the vegetation, they are exposed to winds from both directions. If blowouts are extended in a landward direction, there cannot be very effective winds from that side. Some types of dunes are much better recorders of wind directions than others, some give only a very rough indication or net resultant.

Mainly, the dunes indicate the direction of winds strong enough to move the sand. It might be possible that a wind from one direction would be considered the prevailing wind in terms of time, but might not be strong enough actually to move the sand, while an occasional wind from another direction might be above the critical velocity necessary to move sand. In such a case, the direction indicated by the dunes would be that of the occasional winds. The only winds of significance in dune building are those strong enough to move the sands.

In less arid regions some consideration must be given to the time of year when the strong winds blow in reference to the amount of evaporation and rain. Although it has been reported that even moist dune sands can be blown by winds of sufficient velocity, ordinarily sand is moved by winds free from a great amount of precipitation.

A PRELIMINARY INVESTIGATION OF SHIFTING BEACH PROFILES

Henry C. Stetson
Woods Hole Oceanographic Institution

Contract Nonr-1254(00)
Task NR 388-018

The purpose of this investigation is to map the changes in the beach profile throughout a twelve month's period, choosing portions of the Massachusetts coast where a variety of beach environments could be found. The exposure, that is intensity of wind and sea conditions, the abundance of supply of sand and the proximity to the source, the slope of the offshore bottom and the depth of water are all factors that exercise a control over the resultant form. Furthermore, the rapidity with which a beach changes shape, and the shape which it assumes are likewise controlled by them.

For this investigation the terminology adopted by the Beach Erosion Board is used and the term beach profile includes the backshore, the foreshore, and the offshore portions. They must be considered as a unit. The entire beach profile is mobile and varies constantly. Strictly speaking, observations are only good for the time when they are taken. It is becoming apparent, however, that certain broad patterns are repetitive, that these patterns may be seasonal, and that by continuous observations on selected traverses, certain principles can be established concerning the responses of different types of beaches to the various forces which control their form. On most beaches at any given time there will be features which are hold-overs from a previous set of conditions and which are in the course of being modified. Spot observations of any given beach are, therefore, of limited value and only by a continuous series can the evolutionary sequence be unraveled.

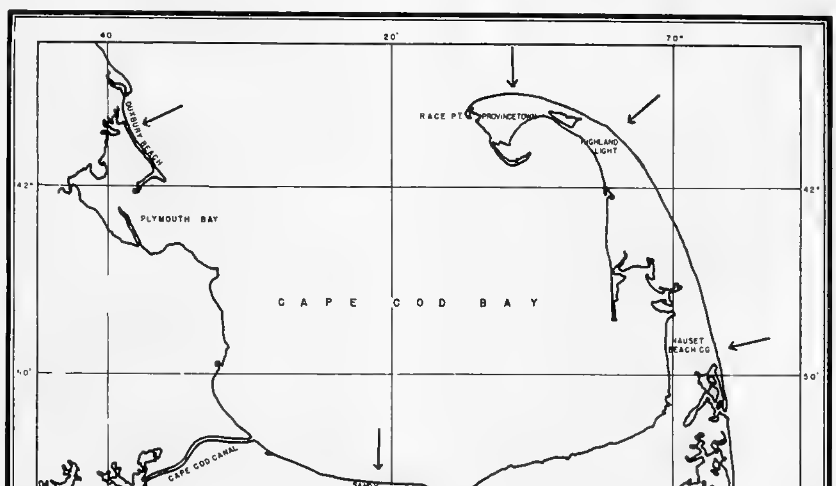

Figure 1. Locations of the traverses.

The following locations were chosen for this study. On the Atlantic side of Cape Cod traverses have been maintained at the following places; Nauset Coast Guard Station, the abandoned Highland Light Coast Guard Station, and about three-quarters of a mile west of the Race Point Coast Guard Station. The first site is a traverse off the southward growing spit which protects the Eastham-Orleans shore, the second is off a cliff section which is shedding debris of all types, and the third is off the north side of the Provincelands section where the shore is being prograded by a succession of beach ridges and offshore bars. The exposure to onshore gales is severe and is about the same on all three, although the tidal currents run stronger off the Race Point traverse. Wave action is as violent as you can find anywhere on the Atlantic coast. On the Cape Cod Bay side, two traverses have been maintained: one at Sandy Neck, Barnstable, and the other at Duxbury Beach. On neither of these beaches is wave action as violent as on the outer Cape, although wind velocities are probably as high and dunes have been extensively developed, especially at Barnstable. Geologically, both are wave-built spits. In the case of Sandy Neck, the source of the sand is the cliffs north of the Cape Cod Canal, but at Duxbury the source is not apparent, possibly coming from the bottom off shore. Both seem relatively stable and have exhibited little topographic change from year to year. They present a marked contrast to the outer Cape where every storm brings marked alterations in width of the backshore and in the position and height of the berms, as well as shifts in the offshore bars of the seaward portion (Fig. 2).

For any given set of environmental controls, looked at in the large, there is a corresponding form which any given beach tends to assume, although it may change temporarily and in response to seasonal alterations in the environment. The profile will not be permanently altered unless the controls, such as supply, also change permanently. The more rigorous conditions of winter cause the most rapid fluctuations, and it was for the purpose of charting these shifts and the return to equilibrium conditions that a twelve-months' period was decided upon for the observations. There is a strong possibility that any given beach will tend to develop what might be termed seasonal characteristics, which may be repeated in response to changing weather conditions as the seasons succeed each other. It may well be that conditions observed in one winter may be used as predictions for what may be expected in subsequent winters.

Figure 2. The outer beach of Cape Cod looking north. Note the marked variations in width and the position of the offshore bars as marked by the line of breakers.

Field work has been carried out in the following manner. The form of the emerged portions of the beach, that is the backshore and the foreshore, is surveyed with a transit and the offshore portion is sounded from a dory with a hand lead and a marked bamboo pole. A permanent baseline of 600 to 1000 feet has been staked out depending on the curve of the shoreline. The seaward portion of the traverse is about 1500 to 2000 feet long, and the boat's position upon it is cut in with the transit up to 60°. Every time a sounding is taken flag signals are made by the boat's crew and acknowledged by the instrumentman. On the Race Point and Highland traverses, parallel profiles 400 feet away are being run this winter [Feb. 1954], as the position

and shape of the bars are thought to vary considerably in a short distance horizontally. The boat's course off shore is maintained by permanent range markers set up on the beach, dunes, or cliff. Occasional echo sounding profiles have been run into deeper water from the outer ends of the traverses with one of the Oceanographic's smaller power boats to supplement the above data. It is not expected that any changes in bottom topography will be recorded in water deeper than is found over the outer ends of the traverses, which is about 40 to 50 feet. Bottom samples are also taken on the emerged and submerged portions of each beach not only to get an over-all picture of the texture but also to determine, if possible, the relationship of texture to slope and to other changes in the topography.

As was expected to be the case, summer conditions were very stable. The easterly storms of that season were neither heavy enough nor of long enough duration to produce significant changes in profile. In fact, it seems probable that the profile of early summer can be counted upon to last with very little change at least until the heavy gales of late fall and early winter begin.

The profiles figured here were chosen as examples of the type of surveys made and on which some change has been observed, rather than as illustrative of any fundamental trends. A delineation of the cyclical change which these beaches go through, if it is a cycle, can be made only after the twelve months of observations have been carried out. It is expected that these beaches will return to the profile observed during the summer months after having gone through many variations; but this has never been established for any beach regime (Figs. 3, 4, 5, & 6).

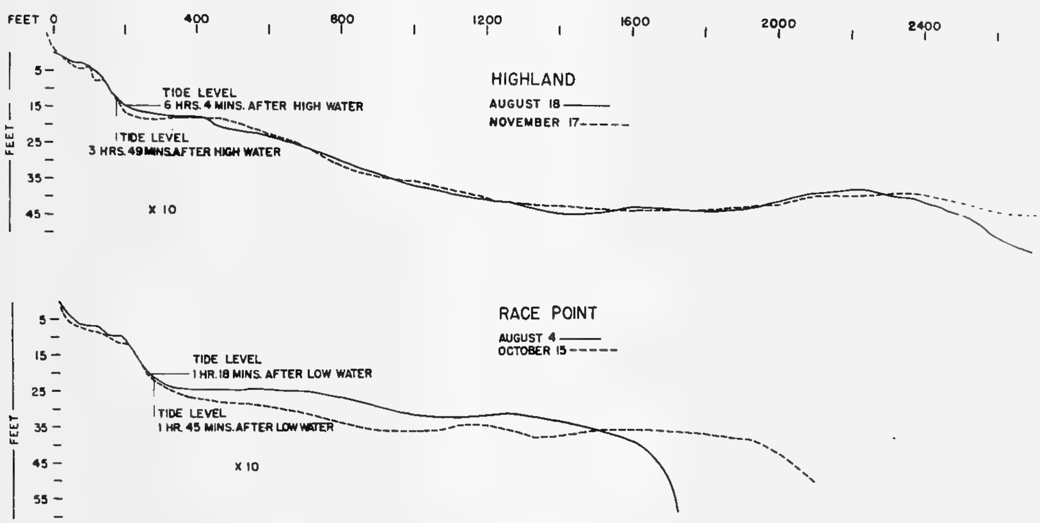

Figure 3. Highland traverse showing cut and fill on the emerged and submerged portions. Note cutting of berms for the dotted traverse but no significant trends in the offshore portion. Race Point Traverse shows smoothing of berms and also a very marked excavation and seaward fill of the offshore section.

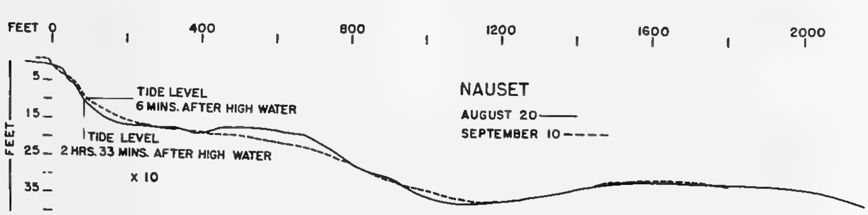

Figure 4. Nauset traverse showing removal of an offshore bar.

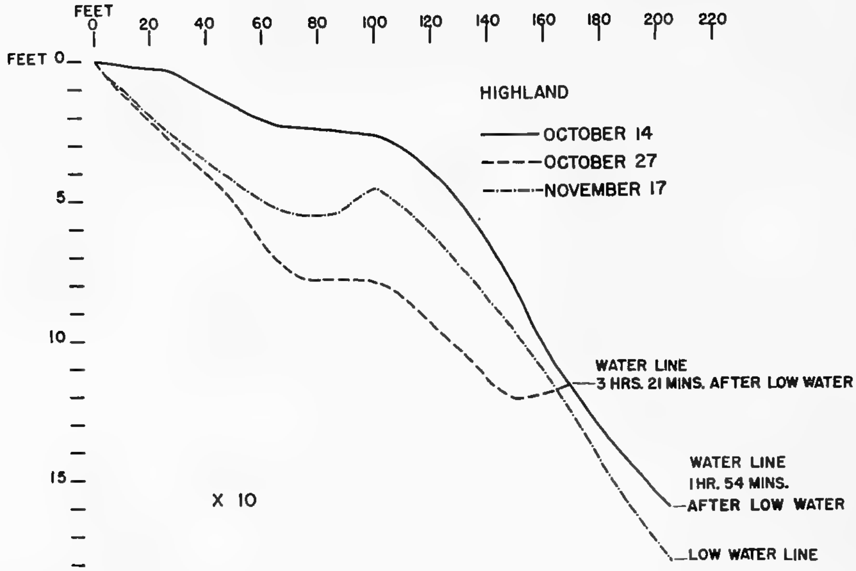

Figure 5. Highland traverse showing changes in the foreshore and backshore. Note the marked cutting between Octobe 14 and 27, with partial restoration by November 17.

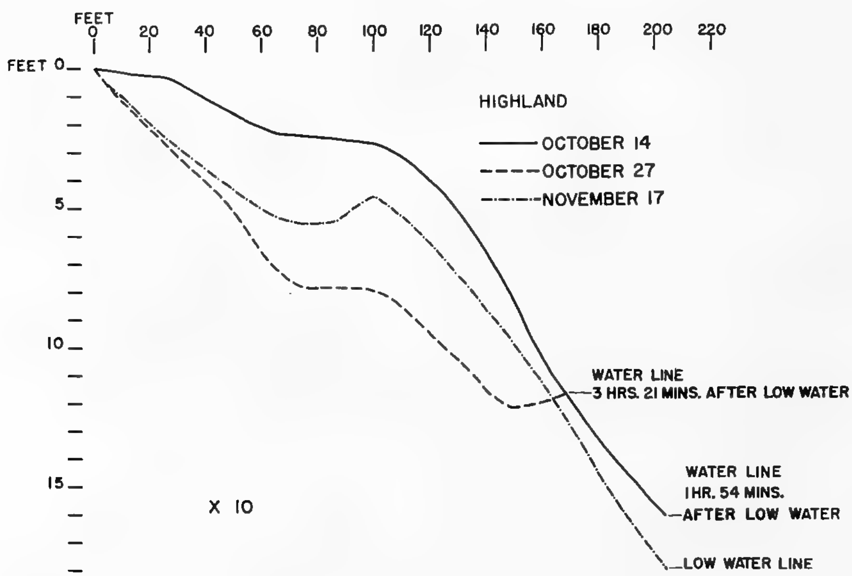

Figure 6. Duxbury traverse showing slight fill on the backshore and cutting on the foreshore. This is a relatively stable beach.

The emerged portion of the profile also shows considerable change of form. One of the most striking features which may appear very suddenly is a steepening of the beach profile with the cutting of a vertical scarp at the seaward edge of a berm. This scarp is usually of small dimensions but may, on a steep beach, be several feet high and, because the sand is loose, difficult for a man to scale. It cannot be stated at present with any degree of certainty just what wave conditions are responsible for this cutting on the beach face but they are thought to be correlated with short, steep seas (Figs. 7 & 8).

A series of aerial photographs have been taken on four flights from a PBY which is attached to the Oceanographic Institution. The flights covered the entire length of the outer Cape

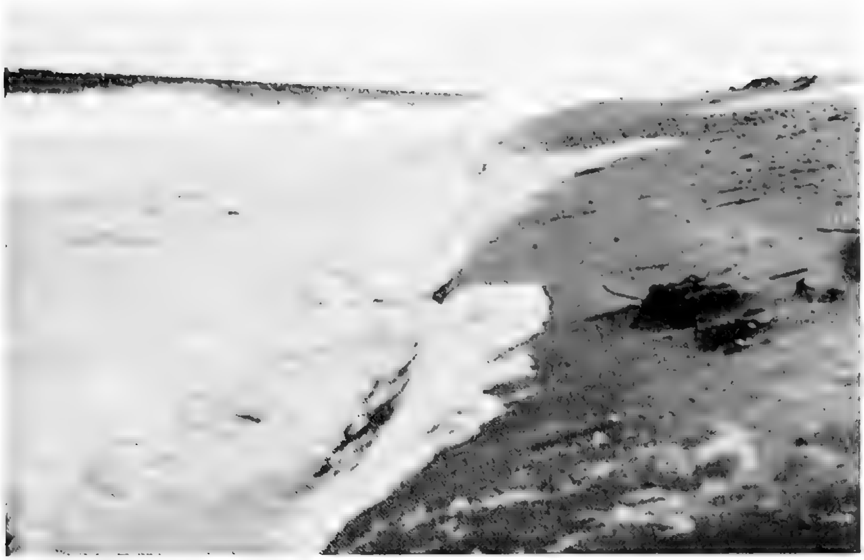

Figure 7. High water at the Race Point Traverse showing the berm beginning to be cliffed by a thirty-mile northwest wind, January 1, 1954.

Figure 8. Low water at Race Point Coast Guard Station, showing a more extensive cliffing in the berm caused by some previous blow. Note the light snow cover which has been removed to the last high water mark, January 1, 1954.

and all of Sandy Neck and Duxbury Beach. Although these photographs are not entirely satisfactory as they were taken with a hand-operated Graflex, they do give some idea of the changing configuration of the beach outline and of the offshore bars. One of the difficulties of using aerial photographs for beach work in this region is the steepness of the offshore portion bringing relatively deep water close inshore which obscures the bars unless marked by breakers. Furthermore, the water in the Gulf of Maine often contains considerable amounts of plankton resulting in low visibility.

The equipment for the field work has proved entirely satisfactory. The jeep with oversized tires can tow the trailer with the dory to any necessary location, sometimes over dune country. The dory has proved entirely practical for taking soundings, and rowing has the advantage over a power boat for sounding on a range because it can be better controlled. It can be launched from the beach except when the bars are breaking heavily which would preclude sounding even from a DUKW. Sounding with a pole and a hand lead is probably more satisfactory in these waters than a portable fathometer would be. In smooth water the fathometer would be superior but such is rarely the case on the outer Cape. With a rough or lumpy sea it would be very difficult to sort out wave heights on the fathometer tape from bottom irregularities.

The sites for the present traverses were chosen because they represent what might be called "simple" or average sections of the shoreline. Serial observations of the regimen at such places are necessary for a basic understanding of the full beach cycle before more complicated cases are considered. The continuation of this study in addition to the present traverses will include the following areas where the beach is prograding rapidly and shoals and spits are forming. From Wood End to Long Point, the section of beach which encloses Provincetown Harbor, growth is taking place by the extension of large, steepsided beach ridges, overlapping at their distal ends. At Race Point Light the beach is prograding by the addition of ridges and swales in a seaward direction. Nauset Inlet is an illustration of two complex spits which are attempting to grow across an inlet where there are strong tidal currents. The amount of sand supplied by beach drifting and longshore currents is large. The result is a complicated series of recurving spits with their attendant shoals which are constantly shifting. The situation provides a good example of a balance between erosion, transportation, and deposition. Beaches constitute one of the most mobile of landforms and one which may change radically in a matter of a few hours. They are never static.

SUMMARY OF DISCUSSION

Matters relating to grain size and sorting were discussed. It was suggested that along a stretch of coast there would be marked changes in size of materials. To determine this, samples are being taken both off shore and on the emerged portions each time the beach profiles are surveyed. The samples are being studied to discover any correlation between slope and grain size and shape. In general it is recognized that the flatter the beach, the smaller the grain size.

Figure 9. Field equipment.

CLASSIFICATION AND IDENTIFICATION OF COASTAL ZONES OF THE WORLD

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Contract Nonr-233(06)
Task NR 388-013

Throughout the day we have listened to descriptions and studies of detailed areas of specific regions, of things that one might say are concerned more, I hope, with fact than with fancy. I find myself now in the predicament of attempting to describe and classify all the coasts of the world. This is indeed a problem of great complexity because we are dealing not only with an aspect of the entire earth but with all the variation of climates and processes that operate upon it, as well as with one of the most dynamic interfaces on its surface—the boundary between land and sea.

This study was taken on as an applied project, one which would be of direct and pertinent significance to the military. As I envisage the project and the goal we are attempting to achieve, it has become one of primarily establishing communication: the development of a common language between groups of people of diverse backgrounds and interests.

Communications have always been one of the more difficult problems in military affairs. The anecdote I treasure in this regard is one that appeared in a recent issue of the "American Scientist," which dealt with the life of Lord Rumford, a leading British scientist of the period of the American Revolution. I had not known that he was of American birth, and had quite a career and variety of interests in the United States. As a Loyalist, he refused to take up arms against his king, went to England, and was quickly depressed by the deplorable state of communications then existing in the Royal Navy. One of the less publicized episodes, I am sure, had to do with a time when the British Fleet sighted the French on the horizon. The admiral hoisted a signal, probably some spirited remark, such as "Engage the enemy and they are ours," whereupon to his dismay the fleet lowered its sails, broke out the small boats in a hurry and these rowed furiously toward the flagship, under the impression that the signal read, "Today is payday."

Difficult as communications may be within the military frame of reference, the problem becomes even more acute when we attempt to communicate from one field to another. In science, it seems to me, the basis of communication is classification—and from this the development of a working nomenclature. If there was any hallmark of 19th Century science, perhaps as contrasted to what we think of science today, it was its overwhelming concern with setting up classifications of birds, rocks, insects, people, etc., etc. The prevailing belief then was that if you had classified something, you had answered all the basic problems in considerable measure.

Today I think we have gone on in many fields to attempt to find the answer to the more fundamental question of "why," rather than simply "what." Although coasts have been classified in one fashion or another for quite some period of time, perhaps as much as a century, most geologic classifications are based on the geologist's primary concern with genesis. The chief question he seeks to answer is how did this thing happen, a concern of little interest to the practical person, who instead wants to know what is going to happen when he makes changes in the natural environment. He is not concerned whether the rocks on which he is building, for example, are 2,000,000 years or 2 years old.

The classification of shorelines now used in almost all textbooks is the one promulgated by the late Professor Douglas Johnson, who placed major emphasis on emergence and

submergence. His classification becomes extremely difficult to apply in a military sense, because it forces the user to make a decision—namely, did this coast rise or sink or remain static with respect to sea level—that has little relevance to the problem at hand, which is the determination of those characteristics of a given coast that are of strategic significance. Secondly, the classification itself encounters difficulty because sea level is such an inconstant datum—the last significant change has been a world-wide rise following the melting of the continental ice caps at the end of the Pleistocene. This has had the practical effect of making almost all the shorelines of the world ones of submergence.

An outgrowth, in part, of Johnson's classification, but a much broader extension of it, is a recent book by Valentin, "Die Küsten der Erde." Valentin set up a four-fold approach to coastal morphology, recognizing that there are dynamic processes operating within the earth itself. Some forces tend to elevate parts of the earth's crust, others to depress it. Operating in conjunction with these forces are processes of erosion and deposition which also may cause a shoreline either to advance or to recede. The result is a four-component system that treats land loss or land gain as the resultant of emergence, submergence, construction, and destruction. Unfortunately, the complex interplay of those self-same components is difficult if not impossible to determine in relation to the appearance of most of the world's coasts. In application, then, Valentin's scheme has difficulties similar to Johnson's classification.[1]

In contrast, we have attempted to set up a classification in which the matter of problem-solving might be cut to a minimum, and in which we could arrive at a common means of communication so that people of widely ranging backgrounds end up speaking a common language. This means we should avoid loaded terms, terms that mean different things to different people, or terms that have lost all meaning because they have been bandied around so much they no longer have any special significance.

We are confronted by the fact that we live on a globe, that it has different climates, and that the effects of these climates are expressed in different ways in a pattern often recognizable on the surface of the earth. Of all these secondary effects, the most visible is the carpet of vegetation. If, for example, we take the simplest of all landforms, a plain, then I think all of us know how different that plain will look on aerial photographs depending upon its environmental situation. An arctic plain has an entirely different appearance and complex of operating problems than a tropical plain.

The accompanying tables are the outgrowth of an as yet uncompleted attempt to recognize these environmental factors and arrive at a workable coastal classification that will include all the elements of our scheme. The first table (Fig. 1) is a classification of those coastal types that are determined by the major landforms present in the coastal strip extending some 5 to 10 miles inland. For that reason the character of the gross structure involved is indicated in the names of the coastal types, which stand out in bold letters. The agents shaping these structures are listed across the top of the table, where they are grouped according to broad zones of climatic influence. The two dominant agents, ice and running water, are given the leading positions.

Obviously some of the processes and landforms do not conform ideally to such a simplification as this, and examples of these are the work of the wind, of organisms, and lastly the results of processes originating within the earth, such as volcanism. But at least I believe that we can resolve most of the coastal landforms of the world into a relatively small number of structural types that can be placed in climatically controlled environments.

It is now our hope—and this is only a progress report—that we have evolved a system that appears to be working and which fits the facts. If this is the case, our next move will be to reduce the classification to a symbolic code that can be used to represent the leading coastal landforms of the world on a map at a scale of approximately 1:25,000,000.

For example, a pattern of closely-spaced horizontal green lines within the dotted outline of a coast will tell the user that this is a plain, very nearly at sea level, underlain by layered

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[1]Since this talk was given, an excellent summary and review of the entire problem of coastal classification has been written by C. A. Cotton, "Deductive Morphology and Genetic Classification of Coasts," Scientific Monthly, Vol. 78, pp. 163-181, 1954.

sedimentary rocks, that these rocks are flat-lying, and that the surface of the plain was shaped by ice scour. Therefore, one can expect a wholly different set of operational consequences here than would be encountered on a geometrically similar plain shaped by streams and located in a tropical region.

These coastal types determined by the major landforms present in a 5- or 10-mile wide strip do not convey the whole picture, however, in spite of a rich variety stemming from various combinations of structures and climates. Shore features, though much more limited in areal extent, are often of equal or greater military importance. They are, in effect, obstacles forming a narrow fringe between the open sea and the particular major coastal landform with which they are associated locally. We therefore recognize a second category of coastal types—those determined by shore features (Fig. 2). Properly included in this category are such things as kelp beds. Dense kelp fouls propellors, makes maneuvering of small craft extremely difficult, and otherwise causes serious problems in amphibious operations. Coral reefs belong here too, as a lot of hard-won experience gained in the last war will testify. Tidal woodland in Fig. 2 refers not to mangrove swamps exclusively, because there are other kinds of coastal vegetation that also extend into the sea.

Beaches other than barrier beaches are being excluded from our classification and map because they are the subject of highly detailed operational intelligence studies conducted by the military. Furthermore, a great many beaches are of extremely limited linear extent.

Shore feature coastal types can be shown on the world map by the use of suitable cartographic techniques, though they will necessarily have to be exaggerated for such small-scale

					CLIMATICALLY-CONTROLLED COASTAL ZONES: ZONE OF ICE-COVERED COASTS	ZONE OF GLACIALLY-SHAPED COASTS		ZONE OF FLUVIALLY-SHAPED COASTS OF HUMID REGIONS	ZONE OF COASTS OF DRY REGIONS	TROPICAL MARINE ZONE	IN ANY ZONE AS APPLICABLE
	LANDFORM CLASS			STRUCT.-LITHOLOGY / PRINCIPAL AGENT	ICE	GLACIERS		RUNNING WATER	WIND	CORAL	VOLCANISM
MAJOR COASTAL LANDFORMS	PLAINS	CONSTRUCTIONAL PLAINS		RELATIVELY FLAT-LAYERED	ICE PLAIN	ICE-DEPOSITION PLAIN		ALLUVIAL PLAIN DELTA PLAIN	EOLIAN SAND PLAIN	CORAL PLAIN	VOLCANIC PLAIN
	PLAINS	DESTRUCTIONAL PLAINS		REL. FLAT-LAYERED: SEDIMENTARY ROCKS		ICE SCOURED PLAINS	SEDIMENTARY PLAIN	STREAM ERODED PLAINS			
				REL. FLAT-LAYERED: VOLCANIC ROCKS			VOLCANIC PLAIN				
				COMPLEX			COMPLEX PLAIN				
	UPLANDS	DESTRUCTIONAL UPLANDS	HILLS	REL. FLAT-LAYERED: SEDIMENTARY ROCKS		ICE SCOURED HILLS	LOW "SEDIMENTARY PLATEAU" REMNANTS	STREAM ERODED HILLS			
				REL. FLAT-LAYERED: VOLCANIC ROCKS			LOW "VOLCANIC PLATEAU" REMNANTS				
				COMPLEX			COMPLEX HILLS				
			MOUNTAINS	REL. FLAT-LAYERED: SEDIMENTARY ROCKS		GLACIATED MOUNTAINS	HIGH "SEDIMENTARY PLATEAU" REMNANTS	STREAM-ERODED MOUNTAINS			
				REL. FLAT-LAYERED: VOLCANIC ROCKS			HIGH "VOLCANIC PLATEAU" REMNANTS				
				COMPLEX			COMPLEX MOUNTAINS				
			PLATEAUS	REL. FLAT-LAYERED: SEDIMENTARY ROCKS		GLACIATED PLATEAUS	SEDIMENTARY PLATEAU	STREAM-ERODED PLATEAUS			
				REL. FLAT-LAYERED: VOLCANIC ROCKS			VOLCANIC PLATEAU				
				COMPLEX			COMPLEX PLATEAU				
		CONSTRUCTIONAL UPLANDS		RELATIVELY FLAT-LAYERED	ICE PLATEAU				EOLIAN SAND HILLS	CORAL PLATEAU	LAVA PLATEAU VOLCANO

Figure 1. Classification of Coastal Types Determined by Major Landforms (By J. T. McGill)

representation. They can be indicated, for example, by narrow color bands in contrast with broad color bands denoting the associated major landform coastal types.

We are now in the process of adding a third element to our coastal classification, and this will be essentially a climatic pattern as exemplified by the characteristic type of vegetation. This, I believe, we shall represent by numbers or by some kind of symbol or color scheme overriding the symbols for coastal types. These environmental categories will be selected on the basis of type areas, such as the Visayan Type or tropic grassland, Malayan Type or evergreen rain forest, etc., in order to give them geographic relevance. They will be chosen as nearly as possible to be representative of really distinctive and readily recognizable climatically similar areas. In other words they can be used as analogs for predicting operational problems in inaccessible areas.

In summary, the proposed world map will show, in a landward sequence, the nearshore and shoreline conditions, the character or major landforms and vegetation in the coastal strip, and then the extent of climatically similar regions over the continents. This will provide a picture, we hope, that when interpreted will bring much-needed information into the strategic planning of landing operations. To restate our goal, it is to build a workable classification using simple, meaningful terms that will convey some understanding of operating conditions to people not necessarily trained in the military evaluation of terrain. Finally we want a classification of coastal forms that is based almost entirely on their representation as seen from the air. The aerial photograph is unquestionably the most powerful tool in our possession today, and this classification is intended to aid photo interpreters.

The oblique air photographs that follow are all from one region, the coast of southern California, much of which is reasonably representative, we believe, of what might be described in the first step of our scheme as complex hills. This is in considerable part a dry region, which means that most streams are intermittent and do not supply a large volume of sediment to the sea. As a consequence, beaches are relatively thin. Long stretches of the coast are bordered by bare rock whose ledges can be traced into the sea (Fig. 3). The strike of the rocks on land commonly is reflected in their seaward continuation by kelp, a plant which introduces a second operational problem on a coast such as this because it is commonly quite difficult to get small landing craft ashore through this marine growth. Bedrock crops out practically everywhere on the surface of the ground inland. Some rocks are stable and hold up well, as in the

<table>
<tr><td colspan="3"></td><td colspan="4">IN CLIMATICALLY-CONTROLLED COASTAL ZONES AS LOCALLY APPLICABLE</td></tr>
<tr><td colspan="2" rowspan="2"></td><td rowspan="2">PRINCIPAL AGENT / SHORE ZONE</td><td rowspan="2">SEA</td><td rowspan="2">WIND</td><td colspan="2">ORGANISMS</td></tr>
<tr><td>CORAL</td><td>VEGETATION</td></tr>
<tr><td rowspan="6">SHORE FEATURES</td><td rowspan="3">CONSTRUCTIONAL FEATURES</td><td>BACKSHORE</td><td></td><td>COASTAL DUNES</td><td></td><td></td></tr>
<tr><td>FORESHORE</td><td>TIDAL MUD FLAT</td><td></td><td>FRINGING OR BARRIER REEF</td><td>TIDAL WOODLAND</td></tr>
<tr><td>OFFSHORE</td><td colspan="2">BARRIER ISLAND, BEACH OR SPIT</td><td>ISOLATED REEF</td><td>KELP BEDS</td></tr>
<tr><td rowspan="3">DESTRUCTIONAL FEATURES</td><td>BACKSHORE</td><td>SEA CLIFF</td><td colspan="3" rowspan="3">NOTE: "SHORE FEATURE" COASTAL TYPES ARE ASSOCIATED WITH MAJOR LANDFORM COASTAL TYPES. COMBINATIONS OF BACKSHORE, FORESHORE AND OFFSHORE TYPES OCCUR LOCALLY.</td></tr>
<tr><td>FORESHORE</td><td>- - - - -</td></tr>
<tr><td>OFFSHORE</td><td>MARINE BENCH</td></tr>
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Figure 2. Classification of Coastal Types Determined by Shore Features (By J. T. McGill)

terraces adjacent to the shore. Shales, on the other hand, and especially those with a high content of volcanic ash, often fail through landsliding, as in the area near the center of the photograph. Such ground is quite unstable for military operations.

Figure 4 shows a mountainous coast in the same region. Here again are a set of operating problems that we hope can be set forth in tabular form and that can be recognized by a relatively

Figure 3. Stream-eroded complex hills, dry region. Coastal terraces on Palos Verdes Hills, Southern California. (Spence Air Photo)

Figure 4. Stream-eroded complex mountains, dry region. Seaward slope of Santa Ynez Mountains, Southern California. (Spence Air Photo)

inexperienced interpreter. If he can locate himself on the proposed coastal map of the world and can relate his picture to our tables and illustrations, he can set up a pattern of more or less predictable events that he will encounter, such as the following, which are typical of this particular region: offshore kelp, rocks, narrow beach, small intermittent streams, rock rather than soil, sparse vegetation, and vegetation whose distribution is controlled to a marked degree by the kind of rock. The terrain in the foreground is underlain by shale, a rock that is relatively

Figure 5. Alluvial plain margin, dry region. Coastal swamp and lagoon near Point Mugu, Southern California. (Fairchild Aerial Surveys, Inc.)

Figure 6. Coastal dunes, dry region. Coastal dunes near Casmalia, California. (Spence Air Photo)

impermeable, which means that water does not sink into it very far. The result is that seasonal vegetation with short roots, such as grass, dominates. Back in the mountains where the rocks are more permeable, slopes are mantled by a permanent vegetative cover of thick, thorny shrubs and bushes that are virtually impenetrable. The fire hazard is very high during the summer dry season, and fire in this country introduces all sorts of operational difficulties that will not be encountered in a more humid region.

Figure 5 is a good example of the complexities that must be faced in setting up a classification. An excellent beach fronts the shore, but its value is reduced by the coastal lagoon and tidal marsh that constitute a formidable barrier denying access from it to the land, as well as by the fact that it can be taken under observation and fire from the nearby mountains. The mountains have about the same structure and vegetative pattern as those in the preceding photograph and like them are characterized by a high correlation between rock type and the distribution of the plant cover.

The coast shown in Fig. 6 is for the most part an extension of Professor Smith's talk. In fact he showed a slide of essentially the same region as this, not far from Santa Maria, California. This is a very exposed coast. Landings are difficult, but are possible. Once ashore the problem of dispersal is paramount, and getting rid of the mountains of gear that any amphibious operation requires must be a first order of business. All men and supplies are in an exposed position with almost no cover. Troops will encounter very marked differences in trafficability in crossing the fresh beach sand, then rather active dune sand, then vegetation-stabilized older dune sand, until finally solid ground is reached some distance inland.

Figure 7 is an extension of the same problem, but with a further complexity introduced. If a landing is made here and troops cross the shore dunes, they may find access to the interior barred where stream drainage has been blocked by the dunes and water is ponded. Between the coastal dune belt and dry ground inland there is a moat of marshy, low-lying ground. A photo interpreter without too extensive a background of experience should be able to read these major terrain characteristics from the photograph if he has the proper guidance. We hope to provide him with that guidance by means of a classification which has a rational, scientific, and genetic basis, but one that is cast in empirical rather than theoretical terms so that there will not be a breakdown in communications.

Frankly, I should have been much happier if we could have turned this problem around the other way and made a number of regional studies from which we could have built a body of

Figure 7. Coastal dunes, dry region. Dune lakes near Oceano, California. (Spence Air Photo)

theory. In a sense we could have piled up a lot of bricks and ultimately made a structure out of them, instead of possibly constructing a pyramid resting on its point. At the moment we are in the unfortunate position of having to build an intellectual edifice with almost no foundation of actual field studies. But since time is of the essence, I believe we are justified in attempting a first approximation at a classification, inadequate as it may be, than to strive for perfection through several decades of field work. Then with the benefit of constructive criticism from the users of our system we may achieve something of really practical value.

SUMMARY OF DISCUSSION

The scientific basis and the purposes of this coastal classification were further defined during the discussion. It was generally agreed that in devising a classification of coasts, consideration should be given to the matter of genesis. In fact, several participants stated that they felt any classification which would be valid in scientific terms would be basically a genetic classification. It was pointed out, however, that the classification need not make explicit the bases used in its development nor require the user to repeat all the thought processes used in developing the classification. The prime objective of this research is to devise a coastal classification of use to photo interpreters, who may not be trained in geology or geography. This classification must provide a means of enabling interpreters to obtain valid answers to military problems without getting involved in problems of landform origins.

The classification has to be workable and easily understood. In setting up the classification every effort has been made to avoid problems of semantics, the use of too highly specialistic terminology and complex definitions, although all the technical scientific bases were thoroughly considered. For example, in considering climate it was felt best to avoid the complexities of standard classifications. A person operating out in the field will not be interested in having to decide whether or not it is a Cw climate. He wants to know whether it's dry? Or is it wet? Or is it very wet? The use of the word "dry" in the coastal classification means what the average person means by dry. There is not much rain. The ground is dry. There is not very extensive plant cover.

The new classification is being applied to the coasts of the world and the results plotted on a single map. The scale requires considerable generalization. However, the map is expected to enable the strategic planner or other user to gain an idea of what would be encountered on a five to ten mile strip inland from any coast. If, for instance, he is concerned with the coast of Kamchatka, the map will give him an idea, graphically, of the offshore conditions he will encounter as he approaches the coast, of the dominant landing conditions, and of the principal coastal landforms with their vegetation cover. Will he encounter a high tidal range? Is it a coast where it does or does not rain a lot? Is it beset by strong winds, or do calms prevail? Is it a foggy coast? Is it icebound? The user should be able to answer all these questions from the information symbolically represented on the map.

Bedrock problems have been minimized as much as possible in this classification. Included are three categories of rock-structure: flat-layered sedimentary rocks, flat-layered volcanic rocks, and the complex. The last category, probably by far the largest, includes complexes of structure and/or lithology, many of which appear to be essentially massive on aerial photographs. This is about as far as the users would want to get involved. They do not want to add research in geology to their other tasks.

A studious effort has been made to avoid producing a classification similar to the kind rather widely used in photo interpretation, sometimes referred to as the "postage stamp classification" with its reference book full of pictures. You have a photograph to identify. You do not know what it is. It has a round shape in it. You go through your book trying to find something with a similar round shape. It is about like matching a Guatemalan issue of stamps. You cannot read Spanish, you do not know who El Presidente is, but you have a picture of him and look through your Scott catalog until you find a similar face. Ergo, this must be it.

The final product of this research will include numerous elements. First is the ancient genetic framework of the coastal strip, the kind of rock, the grass structure, and the major landform. These are physical combinations that have world-wide applicability. On the

framework are superimposed the regional or local effects of climatic control; the shaping of the landforms, formation of shore features, and other things that add up to a specific pattern or complex. Included here is the cover of vegetation, often the dominant effect visible on aerial photographs. Then there can be set up an environmental type or regional pattern which will be identifiable in people's minds, because there will be analogies between similar climates on similar terrain. In essence, this will be a physical geography of coasts, so organized that from it can be read the conditions that probably will be encountered, thus alerting and guiding the users of aerial photographs. This is a tool that will be used for terrain interpretation and by people not necessarily trained in this field.